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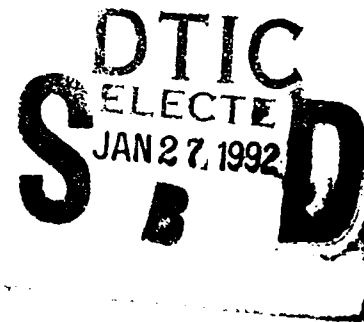
**DESIGNING AN ADVANCED INSTRUCTIONAL
DESIGN ADVISOR: INCORPORATING VISUAL
MATERIALS AND OTHER RESEARCH
ISSUES (VOLUME 4 OF 6)**

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PREFACE

The work reported herein was done for the Advanced Instructional Design Advisor project at the Air Force Armstrong Laboratory (AL/HRT). The substance of this research was done under contract to Mei Associates, Inc., the primary contractor on the Advanced Instructional Design Advisor (Contract No. F33615-88-C-0003).

This work was done as part of the first phase effort on the Advanced Instructional Design Advisor. The initial phase of this project established the conceptual framework and functional specifications for the Advanced Instructional Design Advisor, an automated and intelligent collection of tools to assist subject matter experts who have no special training in instructional technology in the design and development of effective computer-based instructional materials.

Mei Associates' final report for the initial phase will be published as an Armstrong Laboratory Technical Paper. In addition, Mei Associates received 14 papers from the seven consultants working on this phase of the project. These 14 papers have been grouped into six sets and edited by AL/HRT personnel. They are published as Volumes 1 - 6 of Designing an Advanced Instructional Design Advisor:

- Volume 1: Cognitive Science Foundations (AL-TP-1991-0007)
- Volume 2: Principles of Instructional Design (AL-TP-1991-0017)
- Volume 3: Possibilities for Automation (AL-TP-1991-0008)
- Volume 4: Incorporating Visual Materials and Other Research Issues (AL-TP-1991-0017-Vol-4)
- Volume 5: Conceptual Frameworks (AL-TP-1991-0017-Vol-5)
- Volume 6: Transaction Shell Theory (AL-TP-1991-0017-Vol-6)

This is Volume 4 in the series. Sections I and IV were written by Dr. Michael Spector. Section II was written by Dr. Alinda Friedman. Section III was written by Dr. Martha Polson.

SUMMARY

The Advanced Instructional Design Advisor is an R & D project being conducted by the Air Force Armstrong Laboratory in response to an Air Training Command (ATC) Manpower, Personnel, and Training Need calling for improved guidelines for authoring computer-based instruction (CBI) (MPTN 89-14T).

Aggravating the expensive and time-consuming process of CBI development is the lack of Air Force personnel who are well-trained in the areas of instructional technology and educational psychology. More often than not, a subject matter expert with little knowledge of CBI is given the task of designing and developing a computer-based course. Instructional strategies that work in a classroom are often inappropriate in a computer-based setting (e.g., leading questions may work well in a classroom but are difficult to manage in a computer setting). Likewise, the computer offers the capability to present instruction in ways that are not possible in the classroom (e.g., computer simulations models can be used to enhance CBI).

The Advanced Instructional Design Advisor is a project aimed at providing subject matter experts who have no background in computer-based instructional systems with automated and intelligent assistance in the design and development of CBI. The goal is to reduce CBI development time while insuring that the instructional materials are effective.

I. INTRODUCTION (Spector)

The Advanced Instructional Design Advisor (AIDA) is an R & D project aimed at providing automated and intelligent assistance to inexperienced instructional designers who have the task of designing and developing computer-based instruction (CBI). The particular problem being addressed by this line of research is the need for more cost efficient methodologies for the design and development of CBI. Current methods for developing CBI are expensive, time-consuming, and often result in ineffective instruction due to the general lack of expertise in computer-based instructional systems (Spector, 1990).

The Advanced Instructional Design Advisor project is divided into four phases:

Phase 1: Conceptualization & Functional Specifications

Phase 2: Conceptual Refinement & System Specifications

Phase 3: Prototype, Field Test, & Refinement

Phase 4: Technology Demonstration & System Validation

The first two phases have been performed by Task Order Contracts. The third phase is being accomplished via a Broad Agency Announcement (BAA). The fourth phase will be completed by a fully specified contract. The work reported herein concerns the first phase.

The two papers that comprise this report focus on problems of particular difficulty that may be encountered in the process of designing and developing a system to advise and assist inexperienced instructional technologists in the task of building effective CBI. Friedman addresses the difficulties in advising CBI developers about the effective use of graphics. Polson addresses a range of issues raised in the context of CBI development efforts at an Air Force Technical Training Center. Both offer a sobering view of the task confronting the development of an AIDA, but each considers the task possible and worth pursuing.

In section II Friedman argues that we know less about the effective use of graphics than is necessary in order to build a graphics advisor for an AIDA. The common assumption is that more graphics is better. Little regard is given to the particular nature of a graphic given a specific teaching objective and context. She illustrates this point nicely by collecting a series of very different DNA diagrams all of which can be used effectively in a particular context. Given the complexity of the

task of advising a novice how to make effective use of graphics in CBI, she then provides a framework or architecture for an AIDA graphics advisor.

Polson also comments on the graphics problem in CBI. Her sources indicate that the single most time-consuming aspect of developing CBI concerns the development of supporting graphics. She reiterates how inadequate many of the resulting graphics are. Polson goes on to emphasize that designing a graphics mini-advisor is no trivial task and is about as complicated as the task of advising CBI developers about instructional strategies. In addition, Polson identifies several additional problem areas, including CBI evaluation, interactivity, task and instructional analysis, and the human-computer interface. Because each of these areas causes particular challenges for the design of effective CBI, additional research should be conducted in each area as AIDA is designed and developed. For example, having advised a user about an appropriate design for a particular problem is not sufficient. The advice must be presented in such a way that it is understandable, meaningful, and executable.

While the next two sections pose challenging problems that must be resolved before success with AIDA can be expected, they should not be read as posing insurmountable difficulties. Rather, they should be viewed as research agendas to be conducted along with the AIDA project.

II. DESIGNING GRAPHICS FOR COURSEWARE (Friedman)

Background

This research was supported in part by a grant from the Natural Sciences and Engineering Research Council of Canada. I would like to thank Paul Hearty for some very thoughtful and insightful discussions about the area in general, and Martha Polson for her helpful comments on the manuscript.

Designers of instructional systems (automated or otherwise), as well as designers of courseware, often assume that graphic materials and media almost always play a useful and even necessary role in the development of educational materials, and, by inference, in the acquisition of knowledge and skills. However, in reviewing the educational, psychological, and human factors literatures, there is scant evidence to support this view. This chapter surveys these three literatures, and focuses on data relevant to understanding how and when graphic and other non-text representations can support the acquisition of factual knowledge and procedural skills. It then goes on to describe aspects of the human information processing architecture that need to be taken into account in the selection of any media of instruction; this part of the chapter is based upon principles of cognitive science. Third, a framework for the use of graphics in the development of courseware is presented, using data surveyed as well as the architectural considerations. Several of the modules within this framework could be implemented in an automated instructional design system as "mini-experts." Suggestions for research that would provide the necessary information to implement these experts are proposed throughout this chapter.

Introduction

Graphics and other forms of non-text representations undoubtedly play an important role in the acquisition of factual knowledge and procedural skills. It goes without saying, then, that guidelines for the design of courseware, technical manuals, and other instructional materials should include prescriptions for the use of graphics that maximize the efficiency with which individuals learn the material at hand. These guidelines should prescribe, among other things, (a) when using a graphic is preferable to using text, (b) what sort of graphic representation (realistic; schematic; etc.) is best suited to the particular educational applications and goals, (c) what sort of graphical conventions (e.g., that we read figures from left to right) may be assumed to be known by the targeted student population, and (d) when it is desirable for a graphic to be redundant with text information and when it is desirable for the graphic to

supplement the text. Some of these prescriptions will be specific to a particular content area (e.g., in teaching chemistry, some notational schemes are more useful than others), whereas others will generalize across content areas.

In developing an automated instructional design system, such as AIDA, the principles underlying the role of graphics in knowledge and skill acquisition must be incorporated into the system. The system should allow subject matter experts, who may not necessarily be aware of the educational and psychological issues underlying the role of graphics in learning, to make the most efficacious use of graphics in the courseware they develop. In addition, a system for automating the selection of graphics for courseware must be designed to be able to dovetail with those parts of the system in which the course modules themselves are developed. In the theoretical framework outlined in the second section of this chapter, several of the components (e.g., the information parser; the representation analyzer) could be developed as "mini-experts" and incorporated into a larger system. These "mini-experts" can be construed as "graphics technologists" for the system as a whole. However, as will be seen, there exist sufficient gaps in our knowledge about the role of graphics in the learning process that much research is required before such "mini-experts" will be able to inform the courseware development process. Some suggestions for the areas in which research is required are given throughout the discussion.

That educators believe graphics are important for learning is evident from the fact that pictures, graphs, diagrams, symbols, and other non-text information is found in all levels of instructional materials, from first-grade readers to senior- and graduate-level university course materials; the inclusion of graphics in these materials is obviously intended to facilitate learning. Pictorial representations are also ubiquitous in training manuals, consumer products, assembly instructions, and the like; businesses that devise or use such materials operate under the implicit or explicit assumption that it is easier to understand, follow, or remember information that is presented this way. In addition, more and more information in the media available to the lay public is being presented in graphic form, and is meant to be combined with nonredundant information from text, the assumption being that the intended information and the appropriate inferences are acquired as a matter of course.

Despite the widespread use of non-text representations, however, the psychological literature about how adults acquire knowledge and make inferences from graphics is sparse, as are data about how people integrate nonredundant text and non-text information and whether their ability to do so interacts with their level of literacy or their expertise within a specialized domain. For example, comparisons of novice and expert physics

problem-solvers indicate that the use of graphics to present problem information to novices might be contraindicated because the graphics draw attention to superficial problem features (Larkin, McDermott, Simon & Simon, 1980). Yet, most guidelines for constructing non-text learning materials are based on the largely intuitive (and uncritical) assumptions that (a) pictures are good, (b) more pictures are better, and (c) realistic pictures are best of all (e.g., Dwyer, 1972; see Friedman, 1986, Holliday, 1973, and Moore & Nawrocki, 1978, for review).

There is also a lack of research about which aspects of non-text representations best convey different types of information; little is known about the kinds of graphical conventions implicit in many representations (e.g., that we read diagrams from top to bottom and left to right; that size can convey relative quantity; that physical contiguity often implies temporal contiguity); nor is there much information about how these conventions are acquired or best employed in the construction of learning materials. Related to this issue is the fact that there are few empirically-based guidelines about how best to convey different substantive categories of information using graphics. For example, to convey that DNA is structured like a double helix, with two sets of complementary base pairs that separate to form templates for daughter strands, one must convey information about appearances, states and state changes, structures, functions, processes, etc. To do this successfully requires a principled means of choosing one or another portrayal method as being better suited to a particular application. This, in turn, will likely require shifting the research emphasis from concerns about the specific physical characteristics of a particular graphic media (e.g., color or monochrome; drawings vs. slides; large vs. small format) to the type of information that needs to be conveyed and the known (or to be learned) conventions available to portray that type of information.

In the first section of this chapter, I survey the psychological, educational, and human factors literatures relevant to understanding how non-text representations can support the acquisition of factual knowledge and procedural skills. In surveying these literatures, several things became dismayingly apparent. First, for the most part, these are three distinct literatures with different (though occasionally overlapping) sets of emphases, methods, empirical constraints, applied concerns, subject populations, theoretical objectives, and so on. These and other differences render cross-literature comparisons difficult. Second, common to all three literatures is an adherence to the almost uncritical assumption that graphics are better, whether for memory and learning (psychology), conceptual understanding and motivation (education), or ergonomic considerations (human factors). Moore and Nawrocki (1978) discuss several reasons often cited for an adherence to this assumption, including the beliefs that pictures are effective

because (a) they are easier to perceive than verbal stimuli, (b) they can be realistic (the assumption here being that learning should be somehow proportional to degree of "pictorial fidelity"), (c) pictures can decrease memory load (or increase "channel capacity") by providing redundant codes, (d) individual differences in spatial ability are important, so some students will profit from pictorial materials and others will not, and (e) students are more motivated to learn from pictorial materials.

In the present review, it will become apparent that almost all of these reasons are too broadly stated and all can be questioned on empirical grounds. For example, although iconic or pictorial materials might produce better speed and accuracy than verbal materials for some tasks (e.g., perceptual vs. memorial comparisons, Moyer & Bayer, 1976; speeded inferences, Friedman & Bourne, 1976), there are clearly other tasks (e.g., naming words vs. objects, Potter & Falconer, 1975 [see Snodgrass, 1980]) for which verbal stimuli produce superior performance. Indeed, in picture naming tasks, variables such as the frequency in print of the pictures' names have been shown to influence performance (Oldfield & Wingfield, 1965). Similarly, although individual differences in spatial ability should be important a priori in some educational contexts (e.g., solid geometry), they certainly might not be in others, including contexts in which pictures have been shown to facilitate performance (e.g., learning how to identify and classify dinosaurs, Winn, 1982). The main objectives of this chapter are as follows:

- (a) to determine the general conditions under which graphics are an effective educational tool,
- (b) to specify which types of graphics (e.g., line drawings, grey-scale images, photographs, etc.) facilitate learning in particular knowledge and skill domains, and
- (c) to develop a theoretical framework that provides guidelines for the use of graphics in the development of courseware that incorporates the information from the first two objectives.

Limitations of Current Research

All three of the literatures reviewed have limitations. In the psychological literature, the main emphasis has been on how graphical information is perceived and remembered, rather than on how different types of graphics convey different types of information more or less efficiently, or how graphics can be used to best represent information about a particular subject domain, or indeed, what information should be represented to achieve certain educational goals. Thus, the main limitation on the

usefulness of this literature can be characterized by the fact that people investigate, for example, how, whether, or why picture memory is better than verbal memory, but not how, whether, or why pictures should be used in the service of learning a particular topic or type of information.

A second limitation in the psychological literature is that the current emphasis is on trying to characterize knowledge and process differences between novices and experts in a variety of domains, and not necessarily on how expertise is best acquired. Thus, the direct educational implications of such work are often missing. Finally, the research emphasis has been almost entirely placed on the psychological differences that may exist between pictorial representations and other representations, such as text. Comparisons among different types of graphic representations (e.g., photos vs. line drawings) are relatively rare.

Research in education has also focused rather heavily on picture-text differences and physical variables (e.g., large vs. small displays), to the virtual exclusion of such psychologically relevant factors as differences in the type of information to be learned, the interaction between acquisition and testing media, how to determine equivalencies in information content across media, etc. In addition, variations in the subject matter tested, the learners' characteristics, the stimulus variables manipulated, the type of test given, the educational objectives of the research, and many other factors make it exceptionally difficult to make comparisons across studies in this literature, or, indeed, to generalize at all.

As might be anticipated, in the human factors literature the emphasis has been on the principally ergonomic implications of using different display media. In addition, much of the literature is focused on extremely specific applications. Perhaps most dismaying is the tendency to make recommendations in the absence of empirical evidence. Again, this reflects an inherent assumption that the more graphics there are, the more ergonomically sound will be the application. There are a few enlightening exceptions here, though, which will be taken up in turn.

Despite these caveats, each of these literatures has contributed to understanding the role that graphical information plays in acquiring new knowledge and skills. Each has also contributed to the development of the theoretical framework to be presented. In the section that follows, I discuss constraints imposed by the human information processing system architecture and the implications these have for acquiring information from graphic and other media. In particular, I discuss the implications of (a) working memory (WM) capacity limits, (b) the manner in which information is organized and represented in

long-term memory (LTM), and (c) the potential existence of qualitatively different types of processing resources. Within each section, a few selected studies in which learning from different types of graphic media was specifically investigated will be discussed, where possible. The section will close with a section on theoretical and methodological issues that preclude making strong generalizations at this point, as well as with recommendations for future research.

System Architecture

Views regarding the architecture of the human information processing system have changed considerably over the last two decades. Nevertheless, there are three enduring aspects of the system that are relevant to the role of graphics in education: Limits on WM capacity have implications for the use of graphics as organizational aids for memory and problem solving, and also bears on issues of stimulus complexity and the highlighting of information through the use of color or other means. The hierarchical organization of LTM has implications for the perception and comprehension of graphic displays, and LTM representational differences between text and graphics have implications for the attainment of expertise through the use of analogy and metaphor. Finally, the existence of different types of processing resources has implications for the relative efficacy of providing information presented in different media, or to different modalities.

Working memory. Chase and Simon (1973) showed that chess experts can remember about the same number of randomly placed chess pieces as can novices, illustrating that the source of expertise does not rest with differences between novices and experts in some innate or acquired WM capacity. Rather, at least one source of expertise lies in the fact that experts have a vast amount of information stored in LTM about legal configurations of chess pieces; when they view a board that is structured legally with respect to the rules of chess, they can "parse" it into chunks based on these configurations. They then merely need to retrieve the configurations, and generate the pieces that comprise them, at recall. The novice, of course, has no recourse to this strategy. These findings have now been replicated in many domains of expertise, ranging from other types of games (e.g., GO; Reitman, 1976) to more "real-world" situations, such as recall of maps depicting tactical battlefield situations represented by graphical symbols (e.g., Badre, 1982).

There are several implications that the relationship between WM capacity and expertise has for the effectiveness of graphics in problem-solving and learning. To the extent that a graphic representation of a problem facilitates chunking, it should lessen the burden on WM and facilitate problem-solving in domains

for which WM limitations directly constrain solution speed or accuracy (i.e., most real-world situations). For example, Schwartz and Fattaleh (1972) found that when subjects were given deductive reasoning problems in two-dimensional arrays, they solved the problems faster than when the problems were presented in prose form.

A second implication of the relationship between WM capacity and expertise has to do with information acquisition and decision-making. It is not sufficient merely to present to-be-learned information in arbitrary chunks; it is necessary that the chunks be meaningful. For example, Bower and Springston (1970) gave subjects auditory lists of letters to repeat back; identical sequences of letters were chunked into either arbitrary (e.g., IB MPH DFB IX) or meaningful (e.g., IBM PHD FBI X) groupings. Although there were the same sequence and number of letters and the same number of chunks in each case, the meaningful groupings produced much better performance.

Moreover, there is evidence that units of information are best presented in a familiar sequence. For example, Badre (1982) tested the recall of subjects who were experts in tactical decision-making by presenting either meaningfully chunked information in a meaningful sequence, or in the reverse of the meaningful sequence, or nonmeaningful chunks presented in an arbitrary sequence, or all of the information at once. He found that the correct sequence was recalled better than the same sequence in reverse order, which was no different than recall of nonmeaningful chunks. Importantly, recall in the group who received the correct sequence did not differ from that of the group who received all the information on the same screen. Thus, if graphics can be used as aids to chunking information, then they may prove additionally useful if the chunked information can be presented in meaningful, familiar sequences.

These examples illustrate the importance of taking the level of expertise of the subjects as well as the semantics of the stimulus displays into account when investigating manipulations that allegedly make a display more comprehensible. Many investigations of physical variables, such as color coding and stimulus complexity, fail to do this. For example, Knapp, Moses and Gellman (1982) investigated the effect of display complexity on comprehension. They recognized that complex displays might prove burdensome because of WM limitations, among other things, and recommended several guidelines for highlighting information to make displays easier to comprehend. One such suggestion was that a complex display should be segmented to show one segment at a time. However, Knapp et al. (1982) suggested segmenting the displays using a grid; it is likely that a grid might cross an expert's chunk boundary and actually interfere with comprehension. A better approach would be to segment the display into chunks that were based upon units of information that were

meaningful according to some criteria of expertise.

All three literatures under review suggest that under many circumstances, "less is better," which has implications for the role of complexity in graphical and mixed-mode media presentations. For example, Borg and Schuller (1979) showed that subjects who were learning the names and locations of parts of a relatively complex object did better when the inner details of those parts were omitted from the stimulus than they did with a photograph of the actual object. Similarly, Dwyer (1972) found that either simple line drawings or oral instructions alone were more effective than realistic graphics (e.g., shaded drawings and photographs) on tests of drawing, identification, terminology, and comprehension in the domain of heart physiology (his results are quite a bit more complex than this and should be examined in detail). Other investigators have found that less complex stimulus materials lead to equal or better learning than more complex versions of the "same" subject matter (e.g., Moore, Nawrocki & Simutis, 1979), and at least some of these findings are likely to be reflecting WM capacity limitations. There are also studies showing that less complex stimuli are easier to identify from brief presentations than are more complex stimuli (e.g., Ryan & Schwartz, 1956). Thus, it may be that for many applications in which designers have striven for increased veracity of detail in their graphics, exactly the opposite approach is warranted.

On the other hand, there certainly may be some circumstances (e.g., learning a difficult discrimination) in which a complex display is not only warranted, but is necessary. An example of such a circumstance may be found in the work of Marcel and Barnard (1979). They showed subjects pictographic sequences of various actions and the states that would result from those actions, using an experimental apparatus that actually paralleled the actions and states of a pay telephone. The pictured instructions could show either the part of the apparatus that was relevant to each particular step in the sequence, or else it could show the entire (more complex) apparatus at each step. Subjects who received only relevant part information produced poorer verbal descriptions of what the instructions meant and also performed the task more poorly than subjects who received pictures of the entire apparatus. One possible explanation for this finding is that Marcel and Barnard (1979) did not parse their graphics properly, so that their "part" information did not include information necessary to place the parts in context. A more interesting possibility is that Marcel and Barnard's subjects were novices trying to learn a procedural sequence, whereas, for example, Badre's (1982) tacticians, whose performance did not suffer from their having received partial information sequentially, were experts trying to integrate declarative information over time.

Related to the issue of stimulus complexity is the issue of whether using color in displays can contribute to their perceptibility or comprehensibility (Dwyer, 1975; El-Gazzar, 1984; Lamberski & Dwyer, 1983; Luder & Barber, 1984; Reid & Miller, 1980; Stone, 1983). For example, Reid and Miller (1980) had children write descriptions of the subject matter of either monochrome or colored photographs of biological subjects. They found both positive and negative effects of color, and both were due to what they believe is the ability of color to act as a distractor. The positive effects were that color displays yielded less of a tendency to merely name (identify) objects or their parts, which has been interpreted as a less optimal outcome than an actual description. The main disadvantage of the addition of color to the stimuli was that it tended to distract subjects towards describing features that were less biologically significant. It should be noted, however, that the photographs used by Reid and Miller (1980) were of the objects in their "natural" state; that is, they represented appearance information rather than assisting chunking. In principle, color coding might be used to highlight parts of displays that are significant, thus possibly reducing the amount of attention or capacity that might be required to extract this information from a display.

An example of this principle can be found in the results of Luder and Barber (1984), who investigated the effectiveness of redundant color coding in search vs. identification tasks. Redundant color coding refers to the situation in which color is perfectly correlated with some other physical cue (e.g., shape). Luder and Barber (1984) had subjects perform a continuous compensatory tracking task while periodically making judgments about the state of valves in a fuel system. Identification judgments involved questions like "valves 2 and 6 are closed," whereas search judgments involved questions like "there are three valves open." The valves could be in three states (open = green, closed = blue, emergency = red). It should be noted that these color choices are nonarbitrary. It should also be noted that identification of state information (e.g., open) is a subset of the search task.

Luder and Barber (1984) found that identification was faster than search in the monochrome conditions, whereas the reverse was true in the color conditions. Essentially, since the locations of the valves were fixed, redundant color coding offered no advantage over either shape or location for purposes of identifying the valves or their states; however, color did provide substantial gains when subjects had to search for information across the entire display. This is an illustration of the principle that the effectiveness of a particular type of graphic variable will be highly sensitive to the task demands. In addition, the color group performed the tracking task more accurately than the monochrome group in both search and identification conditions. This could be interpreted as meaning

that redundant color coding enabled some capacity (or resources) to be freed for use on the tracking task.

In the framework developed below, general questions such as "when is it better (for learning or comprehension) to use color graphics as opposed to black and white graphics?" are seen as typically inappropriate. Instead, it will be necessary to determine, for example, what the WM requirements of a given task environment are, whether the information to be learned lends itself to chunking, and if so, what are the appropriate chunks to use for the targeted student population. It is only at this juncture that it makes sense to develop instructional materials, via color coding or other means (e.g., highlighting), to try to determine which of several methods facilitates chunking of displays in learners at various levels of expertise. The knowledge gained by this sort of research could be incorporated into a "mini-expert" that would enable courseware developers to use graphics appropriate to how the material to be learned was to be chunked.

To summarize, WM capacity limitations imply that the efficiency of any media for both learning and problem solving will vary as a function of how well-suited or sensitive that media is for transmitting information in chunks or configurations. For instance, unretouched photographs require the viewer to perform all of the chunking operations, whereas photos with irrelevant areas masked out, or with lines drawn around what is to be considered a chunk alleviate this operation. Conversely, any media representation that obscures or otherwise precludes such chunking should interfere with efficient learning and problem solving. It should be noted, however, that in this approach, to test relative efficiency for performance across or within media requires knowing how the information to be transmitted should be parsed into chunks for any given domain and achieved or desired level of expertise. There is a notable absence of research on this issue, although the methodology for determining how an individual has chunked a particular display is reasonably well-established (see Badre, 1982, and Chase & Simon, 1973 for examples).

Long-term memory. Research on the perception, comprehension, and memory of pictorial material has been intimately related to issues concerning the representation of knowledge. Although no single theory of LTM representation has been accepted as clearly preferable to its competitors, some general principles have emerged. Those relevant to the role of graphics in education include the fact that knowledge in LTM is organized, that the organization is hierarchical, and that there are different types of knowledge represented in LTM.

At least three types of LTM knowledge are potentially relevant to studying the role of graphic and pictorial

information in acquiring new factual knowledge and procedural skills : General world knowledge (e.g., Friedman, 1979), domain-specific knowledge (e.g., Hegarty, Just, & Morrison, 1988), and knowledge about graphic conventions that are either domain-specific or not (e.g., Winn, 1982). I will discuss each of these in turn.

Most memory theorists have agreed that there are abstract structures within LTM that represent everyday knowledge about the real world. The term "schema" is often used to refer to these knowledge structures. A schema is a data structure that represents those properties, objects, actions, events, roles, and so on, that are most commonly encountered in a particular instantiation of the schema. The schema for an object, for example, might represent typically encountered visual properties and relations among parts, or it might "point to" procedures that can be used to detect such properties and relations. An object schema might also represent what the object does, where we are likely to find it, and how we can interact with it.

Thus, there are constraints on schema variables that define the range of values it is most likely to have. We know about likelihoods, ranges, and distributions of properties, objects, and events; indeed, this is typically what is referred to as world knowledge. This knowledge is structured hierarchically, and plays an important role in perception, comprehension, and memory of both linguistic and pictorial information.

Both the organizational properties of LTM and the default knowledge represented therein will influence the acquisition of new material. It has been known for a long time that comprehension and memory are both facilitated when new information can be readily organized and assimilated into extant knowledge structures, but the primary evidence for this has come from studies in which information is to be acquired from text (e.g., Haviland & Clark, 1974). That this assertion is true about information presented graphically can be illustrated in several ways. At the perceptual level, Biederman, Glass, and Stacy (1973) had subjects identify target objects in briefly presented scenes that were either coherent or jumbled. This manipulation preserved the amount of "physical" information in the pictures (e.g., contours, brightness changes, etc.) while destroying the semantic relationships among the objects. This means that a high-level schema could not be used to aid identification of the objects. In one study, Biederman et al. (1973) found that even when subjects knew what to look for (i.e., they had been shown the piece with the target object in advance of the slide) as well as where to look, they were still more accurate with the coherent displays than with the jumbled displays.

In a similar vein, Mandler and Johnson (1976) have shown

that subjects remember more about black and white line drawings that are coherently arranged (according to some schema) than they do when given drawings of the identical objects arranged haphazardly. Their results are especially noteworthy because their drawings contained relatively few objects (e.g., 6-8) that were not too detailed, and according to some accounts of visual LTM (e.g., Shepard, 1967) subjects might have been expected to remember them rather well, regardless of how they were arranged.

A final example of how organizing new information makes it more comprehensible and memorable comes from the work of Bransford and Johnson (1973). They showed that prose passages that were virtually impossible to comprehend, let alone remember, could be rendered easy and memorable through the addition of advance information that supplied some necessary contextual and organizational support (see Mayer, 1979, for a review of the role of advance organizers in learning). They were able to demonstrate these effects by providing a title for some of the passages, and for others, by providing a picture that "set the scene" for the actions that were described in the passage (unfortunately, they never compared the two methods directly). In summary, the more that a graphical display can be made to correspond to or take advantage of the way in which information is organized in LTM, the better will the information in that display be apprehended and remembered.

In addition to the role played by the organization of LTM, there are three broad classes of LTM expectations, or world knowledge, that are relevant to the role of graphics in education. The first, of course, is the "everyday" type of knowledge just discussed. Expectations about the world govern what people look at in a picture (Loftus, 1972), how long it takes them to recognize what they see (Friedman, 1979), and the duration of subsequent fixations to the same objects (Friedman & Liebelt, 1981). More generally, when schemas guide perception (as they do in most real world situations), then objects in the environment that correspond to "slots" in an activated schema could be perceived and comprehended relatively automatically. In contrast, without context, or in an unusual context, object identification usually requires more visual details (Friedman, 1979; Palmer, 1975).

One implication of this approach is that people should take less time to identify expected objects than unexpected objects. This should hold for objects in the environment as well as objects depicted graphically. This conjecture has been supported by eye fixation data recorded from subjects who viewed shaded line drawings depicting common scenes and places. First fixations to expected objects were half as long as first fixations to unexpected objects (Friedman, 1979). Since all objects had roughly equivalent amounts of detail, subjects either processed such details more quickly when identifying expected

objects, or, more likely, such details were unnecessary for identifying expected objects in context. The latter interpretation was supported by recognition memory data. Subjects virtually never noticed changes made to the details of expected objects whereas they often noticed changes of details to the unexpected objects. Indeed, changes of details to unexpected objects were noticed more often than when expected objects were deleted altogether.

These findings indicate that the expected portion of a stimulus might be stored as an instance of the particular global schema it instantiates, without regard to specific episodic (occurrence) or descriptive details, since it is not normally useful to take note of such already expected information. Thus, in an educational context, it may be unnecessary, or even detrimental in certain circumstances, to present graphical stimuli that are rich in detail, especially when that detail is only for the purpose of embellishment.

A case in point can be found in the education literature about what is learned from a text that either is or is not accompanied by illustrations. Some authors find that graphics facilitate written or oral text comprehension and memory (e.g., Holliday, 1975; Lesgold, Levin, Shimron, & Guttman, 1975; Pressley, Levin, Pigotte, LeCompte & Hope, 1983; Rigney & Lutz, 1976; Royer & Cable, 1976; Ruch & Levin, 1977) and others find that they do not (Alesandrini & Rigney, 1981; Edyburn, 1982; King, 1975; Lang & Soloman, 1979; Rohwer & Harris, 1975). Haring and Fry (1979) claimed that previous studies were in disagreement because the subjects were different ages, the picture manipulations ranged from one relevant picture per passage that either was specific or general to 37 pictures per passage, the texts varied in difficulty and type (e.g., whether they were narrative or expository), and the measures of comprehension varied from multiple choice to free recall. Using fourth and sixth-grade subjects, they demonstrated that additional details in a picture do not facilitate text comprehension if those details are at a "low level." In the present context, the details they refer to are those that embellish expected items.

The second class of expectations that are relevant to the role of graphics in education is knowledge about the substantive domain to be learned or about domains that are analogous to it. We have already seen, for example, how the amount of information that is acquired from a display is related to the amount of information that can be chunked and held in WM. This in turn, is a positive function of the amount of prior knowledge that the observer has about the domain being displayed and how that information is organized.

Educators take advantage of this principle by exploiting analogies between an already known domain and a to-be-learned

domain. Of interest for the role of graphics in these efforts is a study by Royer and Cable (1976). They were investigating the role of transfer in learning from prose passages and were trying to establish whether illustrations and physical analogies could facilitate transfer. They conjectured that transfer between two passages would require that the first passage somehow be able to establish a "knowledge bridge" to the second. They had college-age subjects read an abstract passage about the internal structure of metals and electroconductivity after reading either an irrelevant (control) passage, another abstract passage about electroconductivity, a passage about the topic that used concrete physical referents, a passage that was abstract but that used analogies to known concepts, or the same abstract passage accompanied by line drawings showing the structural relationships being referred to. The latter three manipulations all improved performance relative to the control group and to the abstract passage, and they did not differ from each other. Thus, it was the concreteness per se that facilitated transfer -- whether by physical referent, by analogy, or by illustration. This study is important because it illustrates that it is sometimes not the use of graphics per se, but rather, a property of graphics (such as concreteness) shared by other media that has benefitted performance. The exact componential aspect of a graphic manipulation that has helped (or hindered) performance has been rarely researched or discussed.

The third class of LTM knowledge that is relevant to the communicative effectiveness of graphics in education is knowledge about graphical conventions (e.g., the use of lines streaming away from a figure to indicate motion; the assumption that we will read a table from left to right, top to bottom; the assumption that occlusion will be interpreted as a depth cue in a line drawing, etc.). That is, in the text comprehension literature a distinction has been made between the knowledge needed to comprehend the events that occur in a story and the knowledge we have about how stories are typically structured (e.g., that a story consists of a setting and episodes; that episodes consist of conflicts and resolutions, etc.; Mandler & Johnson, 1977). A similar distinction can be made for graphical stimuli: a graphic will normally attempt to convey some substantive information, and it will do so using a "grammar" and "syntax" which are assumed to be shared between the designer of the graphic and the targeted observer. This is clearly an area that lends itself to automatization in the development of courseware; in the theoretical framework proposed below, for example, it is the task of the information parser to determine, for a given course module, which graphical conventions can be assumed to be known, and which are novel. When novel conventions are required, the system might suggest to the courseware developer that a submodule be created.

Although there are certainly substantive domains in which

information is principally graphic and in which it is obvious that there are conventions that need to be learned before comprehension is easy or even possible (e.g., map reading, Potash, 1977; radiography, Carmody, 1985; aerial photography, Way, 1973, cited in Perkins, 1980), for most of the domains we are concerned with here, it is not even clear whether graphics are an appropriate means to convey information, let alone which graphical conventions might or might not be appropriate for doing so.

There has not been much systematic research conducted on the relative comprehensibility of various graphical conventions for conveying different kinds of information. Evidence that there are such conventions, and that certain experiences (or training) might be necessary to perceive accurately things that are normally encountered in three dimensions when they are pictured in two dimensions comes from the cross-cultural literature on picture perception (see Pick & Pick, 1978, for a review). Although interpreting cultural differences in picture perception is difficult, in the present context, the etiology of such differences is far less important than the fact that they exist at all. Their existence underscores the importance of not presuming that the conventions implicit in a particular method of depicting information will be known to the audience for which that graphic is intended.

An almost poignant, though revealing, example of the importance of this principle comes from a study by Lang and Soloman (1979), who investigated whether pictures would facilitate the process of learning to read common nouns. In one study, only children who had been told that the pictures were representations of the objects named by the words showed improved performance. Thus, at least for young children, it cannot even be assumed that they understand the conventional use of proximity (and simultaneity in time) to indicate that two things should be taken as having the same referent.

In another example of the role that learned graphic conventions play in acquiring new knowledge, Winn (1982) investigated several means by which diagrams could be structured to convey different types of information. His grade nine subjects were to learn to identify dinosaurs as well as to learn their correct sequence of evolution. All subjects received flow diagrams with dinosaur names; half the subjects saw pictures of the dinosaurs above their names. In addition, for half of each of these groups, the flow diagram presented the dinosaurs in the "canonical" (conventional) left-to-right, top-to-bottom order, whereas the other half received the flow diagrams in the reverse of this "expected" sequence. Winn (1982) found that the conventional order produced better performance on the test of evolutionary sequence than the reverse order, but only for subjects who had received pictures in addition to names. This result is reminiscent of the Badre (1982) findings described earlier. Both findings are especially interesting because they illustrate how entrenched a convention can become; in principle,

a reverse order has identical sequence information as a non-reversed order, yet they are clearly psychologically different.

That graphic conventions are not automatically comprehended, and that such comprehension is necessary for certain types of learning is nicely demonstrated in an experiment by Brooks (1977). She showed second, sixth, and ninth graders 18 black and white line drawings that each contained two normally inanimate objects, one of which was drawn with arms and legs. The objects were shown engaged in interactive relationships, and half the subjects saw the pictures with "action lines," such as vertical lines drawn above an object to indicate that it is falling. It should be noted that, though action lines are not entirely arbitrary (for example, vertical lines are not used to indicate horizontal or diagonal motion), they are nevertheless relatively arbitrary conventions used to depict the direction and amplitude of motion. Brooks' (1977) rationale for the manipulation was that action lines could be used as clues to the interactions between objects if, and only if, subjects understand this particular convention. Thus, older children, who presumably had more experience with comics and cartoons, would benefit from the action lines more than younger children. She found that action lines only facilitated recall for the ninth grade subjects.

Action lines represent an example of a pictorial convention that is acquired relatively late, so that their use as a mechanism to improve the "readability" of a graphic needs to be constrained by this fact. Indeed, several conclusions that may be reached from this literature are that (a) different pictorial devices or conventions need to be explicitly identified, (b) different pictorial conventions need to be scaled along a dimension of "readability," (c) this scale may differ according to the skills and experience of the observers (Perkins, 1980), and, (d) the conventions that might be particular to a given subject matter domain might need to be explicitly taught, much as a mathematical notation is taught prior to (or at least simultaneously with) its use in a proof. Each of these conclusions could easily serve as a focus of future research.

To summarize, the organization of LTM and its representation of world knowledge, special domain knowledge, and knowledge of graphic conventions will clearly have a profound influence on perceptibility, comprehensibility and memorability, both inside and outside of a formal educational context. Thus, media representations that exploit this organization, that take advantage of conventions and default knowledge to make analogies between what is known and what is to become known should facilitate learning.

Processing resources. Until 1979, most accounts of the architecture of the human information processing system assumed that the processes that took place within the system all drew on the same general pool of processing resources (e.g., Kahneman, 1973; Norman & Bobrow, 1975). Then, Navon and Gopher (1979)

wrote a seminal article in which they proposed that the human information processing system probably has access to several qualitatively different types of resources, each of which was limited in amount. Processes that required the same type of resource to execute, when performed together, would have to compete for that particular resource, with the possibility that there would not be enough for all competitors and hence there might be a decline in performance relative to a noncompetitive situation. In contrast, processes that required qualitatively different resources might be able to be executed concurrently with no loss of either efficiency or accuracy.

Navon and Gopher (1979) did not specify what the qualitative properties of different resource pools might be, and indeed, their model is somewhat intractable because it has no mechanism for the a priori specification of which types of resources will be required to perform a particular task. In part as an effort to address this problem, both Friedman and Polson (1981) and Wickens (1984) have proposed multiple resource models in which the nature and number of resource pools have been specified. In Friedman and Polson's (1981) model, two independent resource pools are assumed to exist that are each associated with a particular cerebral hemisphere. In Wicken's (1984) model, separate resource pools are hypothesized to exist for information input to different modalities (e.g., auditory vs. visual), for different types of stimulus codes (e.g., verbal vs. visuospatial), and for different stages of processing (early vs. late).

These approaches are relevant to the role of graphics in education because two longstanding hypotheses in the education literature regarding why the addition of graphics to a text or aural presentation should facilitate information acquisition are that (a) learning is facilitated when stimuli are input to different "channels," which usually is interpreted to mean different modalities, and (b) learning is facilitated when, either because of input to different modalities or because stimuli are of qualitatively different types (e.g., pictures and text), their processing results in more than one code. Both hypotheses are typically tested by augmenting a verbal passage (presented either aurally or visually) with some sort of graphic stimuli (e.g., Nugent, 1982; Pressley, Levin, Pigott, LeCompte, & Hope, 1983; Rohwer & Harris, 1975). From a multiple-resources view, processing stimuli in different modalities or of different types might indeed imply that different types of resources are necessary. The question is whether this is beneficial or not.

Just as the issue of redundancy of codes has been relevant to the literature concerned with the relative merits of color vs. monochrome displays, the costs and benefits of redundancy is an issue in the "multimedia" literature. It should be noted that there can be several types of redundancy, which are often confused. In the "pure" cases, there can be redundancy of input channel, as when pictures and text are presented visually, or redundancy of code, as when the same text is presented aurally

and visually. There can also be hybrids, as when aurally presented verbal material is supplemented by pictures. An example of the latter is a study by Pressley, et al. (1983). They read aloud lists of concrete sentences to second and third graders. The sentences were either presented by themselves, or with pictures that matched their content. They found that the matching condition produced better recall than either of the other conditions, which did not differ from each other. Thus, Pressley et al. (1983) confirmed that pictures that are redundant with the semantic content of a sentence facilitate memory for that content. However, they had no real control over the degree of mismatch; indeed, some of the mismatched pictures directly contradicted the sentences they were shown with. This illustrates an important issue in this literature: How is one to know, either across or even within-media, what meaning is afforded by each instance of a given concept?

Rohwer and Harris (1975) also investigated the effects of presenting information in different modalities and media, and their study is notable because they used single-media control groups. They presented high and low socioeconomic status (SES) fourth-graders with three expository prose passages. In the single-medium versions, the passages were either presented with a tape recorder, or printed versions were presented via slides of the text of the passage, or picture versions were presented that consisted of 10 pictures per passage. In multimedia presentations, all possible combinations of media pairs were presented, as well as a condition in which the information was presented in all three media simultaneously. It should be noted that each passage contrasted two related concepts (e.g., two types of monkeys) on each of five attributes (e.g., type of tail), so that the correspondence between the semantic content of the passage and its pictures was made more feasible.

Although the results of their study were complex, the main findings were that, for single-media, either oral or printed presentations produced better performance than the picture presentation. For combined media, although the outcome depended a bit on the SES of the subjects, both the oral plus picture and the print plus picture presentations produced better performance than the oral plus print conditions. Rohwer and Harris (1975) concluded that presenting the same semantic content in two different codes (or what we have been referring to as "code redundancy") is generally better than presenting the identical (verbal) information to two different modalities.

Nugent (1982) came to a similar conclusion, although from slightly different findings. She pointed out that a medium is seldom associated with only one symbol system. For example, a visual medium, such as film, can be used to display still or animated graphics in addition to text. She conjectured that when semantic information is redundant, then presenting it to different modalities via different symbol systems (i.e., presenting prose to the auditory system and pictures visually) should maximize learning. Using a design similar to that of

Rohwer and Harris (1975), she found positive evidence for this conjecture. In a second study, Nugent (1982) found that when semantic information was nonredundant, then presenting it to different modalities did not augment learning, relative to a single-media control, but neither did it interfere with learning. That is, subjects who received different information orally and visually performed as well as subjects who received only the oral or only the visual information.

There has not been enough research in this area to come to any firm conclusions regarding the role of either redundancy of modality or code in efficient learning. A major problem may be that it is difficult to specify exactly what information is being conveyed by a particular media. This problem will be taken up below.

Theoretical and Methodological Issues

There are several methodological problems that plague the literature as a whole and that require resolution before questions regarding the role of graphics in education can be answered. Indeed, some of these problems preclude making almost any generalizations at all from extant data.

One particularly vexing problem, mentioned above, is that of stimulus equivalence: it is difficult to determine exactly what information is being conveyed by different stimulus materials. This is particularly so when comparisons are made between different classes of representations (e.g., comparisons of text with flowcharts or movies or a series of pictures), but it is also difficult when comparisons are made between two different types of graphic stimuli that are alleged to portray identical substantive information in merely different formats. What is more, very few investigators make an effort to substantiate claims of equivalence by subjecting their materials to norming studies, for example.

The problem of stimulus equivalence between media has been studied in its own right (Baggett, 1979, 1986; Baggett & Ehrenfeucht, 1982). Baggett and Ehrenfeucht (1982) point out that there has basically been no method of preparing information for experimentation which is the same in content but which can be presented in two media (e.g., either pictorially or verbally). Thus, similarities and differences in performance as a function of media of presentation may be due to differences in content, and/or differences in the way the two media convey messages; they certainly may not be unequivocally assigned to media differences.

Baggett (1979) devised a method for constructing a text that was structurally equivalent to a wordless movie (The Red Balloon), insofar as subjects could agree that both the movie and the constructed text contained the same 14 episodes, each with an exposition, complication, and resolution, and that episodic

boundaries in one medium had exactly specified locations in the other. New subjects then either watched the movie or heard the text, and then recalled as much as they could. Recall of structural statements was similar in both media, but there were differences in content recall, which were attributed to different degrees to which different world knowledge was activated in the two groups.

In a second series of studies, Baggett and Ehrenfeucht (1982) specifically tried to equate content as well as structure between a narrative movie (The Unicorn in the Garden) and a text. They developed four measures of empirically-determined content equivalence: (a) ratings of how well-represented each of 350 sentence fragments was in the movie (or vice versa), (b) for each fragment, which photo (taken from the movie) best corresponded to it (or vice versa); termed "bi-directional touchpoints," (c) which of the 350 sentence fragments or photos were in the top 20% in terms of importance to the story, and (d) the similarity of importance ratings of the characters in the two medias. It should be noted that these methods allow assessment of degree of equivalence, and are not limited to comparisons between movie and text media (e.g., two texts or two films could be compared). New subjects recalled the stories, and the summaries based on different media were indistinguishable.

Baggett's work is notable because the development of materials was not based on intuition (as it usually is in this literature) but rather, it was based on several empirical measures. Although it is not clear whether her conclusions will hold in a context in which non-narrative information is to be learned, nor is it clear whether her methods could be adapted to other graphic media, it would be a great help in interpreting research if other investigators would take as much care to determine in what ways their materials were or were not equivalent. Otherwise, any between- or within-media differences obtained are at best ambiguous. Thus, one possibility for future research is the development of methods and measures for assessing stimulus equivalence.

The second methodological issue shall be referred to as domain specificity, and concerns the choice of subject matter to be learned. It is almost overwhelmingly true that either between- or within-media comparisons are made in one and only one subject-matter domain, and often on only one particular topic or lesson within that domain. So, for example, Lamberski and Dwyer (1983) contrasted color vs. monochrome presentations of the physiology of the heart; Holliday, Brunner, and Donais (1973) compared picture-word vs. block-word diagrams of the oxygen, carbon, nitrogen and water cycles; Nugent (1982) compared the efficacy of print, audio and movie media (and their combinations) on the topic of cheetahs; Rohwer and Harris (1975) compared text alone with text plus analogies or pictures for learning about electroconductivity, and so on. The point is that there needs to be much more attention paid to content domains in comparing different media presentations. It would also be useful to

compare more than one topic or lesson within the same domain, so that proper item analyses could be conducted. The ability to generalize findings either within or across substantive domains will be severely constrained unless specific empirical work is conducted to compare these domains. Thus, here is another area that is ripe for future research.

Third, there is a notable lack of research on the issues of (a) what graphical conventions exist or are assumed to exist in the presentation of information from any particular substantive domain, (b) whether these conventions can be taught and if it is helpful to do so, (c) what conventions are being implicitly compared with each other in any given study, and (d) how graphic conventions can themselves be exploited to facilitate information acquisition. These issues have already been discussed (e.g., see Winn, 1981, for an explicit comparison); they become methodological issues for reasons similar to those for issues of stimulus equivalence. That is, if two types of graphics are being compared and some sort of behavioral difference is observed, one needs to determine whether at least one of the reasons is that one type of graphic exploits or enlists a particular convention (known or unknown to the subjects) whereas the other does not. Once again, unless this is known and/or controlled, interpretations of differences between conditions cannot be made unambiguously.

A fourth area of concern has to do with the encoding-test relationship; i.e., the relationship between how information is presented and what sort of knowledge is being tested. There are several psychological principles (e.g., encoding specificity) as well as several studies (e.g., McDaniel, Friedman, & Bourne, 1978; Stein, Morris, & Bransford, 1978) indicating that unless there is compatibility between the way materials are encoded and how they are tested, degree of learning (indeed, even what is learned) may be incorrectly estimated. For example, Lamberski and Dwyer (1983) gave subjects color or monochrome pictures of the human heart, and tested them on terminology, comprehension of heart function, identification of structures, and their ability to draw the heart. They found more of a difference between presentation conditions on tests requiring greater visualization (e.g., identification of structures and drawing). Similarly, Jeon and Branson (1981), who investigated whether movies, slides, or text would be better for acquisition of a motor skill, criticized previous between-media studies on the grounds that many written behavioral measures do not match the instructional objectives (i.e., actual motor performance). They cite Allen and Weintraub (1968) as suggesting that the "use of motion in a display is definitely indicated when the particular content to be learned consists of the movement itself or its characteristics, or where the content is enhanced or differentiated by the cues provided in the action of the movement." Jeon and Branson (1981) found that no differences between acquisition conditions were obtained when subjects were asked to write down the procedure they just learned. On the other hand, the film produced much better performance of the actual task than did either the slides

or the text, and with 37% savings in time to learn. Thus, in addition to the media of presentation, it might be profitable to have routinely several types of knowledge tests.

Fifth, even if investigators attend to the four problem areas just discussed, there is no guarantee that a conclusion regarding the relative merits of a certain type of graphic can be reached unless it is clear that the information being presented has been "packaged" suitably with respect to the particular domain of expertise to be learned and the level of knowledge of the learner. This is the problem of domain parsing. Thus, research on the role of graphics in education cannot really take place outside the context of curriculum research in general.

Conclusions

Each of the issues raised above converges on a principle conclusion: Given the current state-of-the-art, it is probably premature for educators to contrast different media and look for student aptitude by media of presentation interactions. Similarly, it may be insufficient for psychologists to theorize about differences between pictorial and verbal memory as if such differences were generalizable across substantive domains, or for human factors engineers to assert that particular types of media or display technologies will, under all circumstances, be better than others. This conclusion is, by no means, unique to the present article. For example, in a 1973 review of the education literature on pictorial research, Holliday stated that "It is probable that certain kinds of pictures facilitate the learning of certain types of objectives for certain students with certain characteristics. However, the precise relationships have not been established." Unfortunately, the substance of this statement is still principally true.

As stated earlier, most studies investigating the role of graphics in learning and education have tested the effects of supplementing verbal material (usually written text) with representational (i.e., realistic) pictures. The goal has usually been to verify the assumption that graphics increase instructional effectiveness. What seems to be absent from the literature in general is a systematic analysis of what types of information graphical, as contrasted to some other representations, can convey, and under what circumstances or task domains or sets of educational goals it is necessary or desirable to convey this information. Thus, the issue should probably not be stated as: Under what circumstances and with what sorts of learners are graphical media an effective educational tool? Rather, there needs to be more emphasis placed on analyzing the types of concepts to be conveyed within a given subject matter domain, and then to investigate the circumstances in which graphical media can be used to convey these concepts.

It should be clear that, when considered in terms of the architectural hardware of the human information processing

system, the role played by graphics in learning is really no different, in principle, than the role played by text or any other media. Thus, for example, we know that chunking new information, organizing it, giving it contextual support, relating it to prior knowledge, and so on, are all useful devices for facilitating knowledge acquisition. It should come as no surprise that these principles are true across media. What is notably absent from the literature is a sense of the circumstances under which a particular type of media presentation is better than some other type for chunking or organizing or activating prior knowledge. There are no empirical or theoretical guidelines for determining what sorts of information are uniquely afforded by graphics and when it is important to present such information. That is, despite hundreds of studies, the question still remains as to exactly what, if anything, is special about graphics qua graphics.

Theoretical Framework

There is a growing consensus among cognitive scientists that to perform successfully in a particular task domain, a person must have an accurate mental model of that domain. Domains that have been investigated in this context include solving arithmetic or physics problems (Greeno, 1983; Larkin, McDermott, Simon & Simon, 1980), learning to use a hand-held calculator (Mayer & Bayman, 1981; Young, 1983) or a computer's text editor (Egan & Schwartz, 1979; Gentner & Gentner, 1983), and navigating around large-scale environments (Chase & Chi, 1981). If accurate mental models underlie successful performance, then understanding the role of graphics in education requires determining what the relevant mental models are within particular knowledge and skill domains and which type of representations best convey them. Thus, to the extent that mental models can be conveyed with pictures, graphics, diagrams, and the like, then optimizing the use of graphics in education requires a framework that describes the relationship between different types of graphics and different educational goals. This will require a careful analysis of each knowledge domain and a more sophisticated view than has been adopted in the past toward the potential utility of graphic representations. That is, there will likely be some domains for which graphics are the method of choice for presenting information and others in which their use is even contraindicated.

Teaching physics is a good case in point. Physics problems are often conveyed to students with pictorial diagrams of objects like springs, pulleys, inclined planes, etc. Yet this type of presentation may not be optimal because it focuses the student on superficial features (e.g., "This is an inclined plane problem") rather than the physical laws that are relevant to the problem's solution (Larkin, McDermott, Simon & Simon, 1980). Similarly, as discussed in the previous section, there may be certain educational goals (or conveyance needs) for which it is better to use simple rather than complex graphics, or in which the use of

"enhancements" such as color are actually harmful.

In the previous section, I concluded that many issues need to be resolved before the role that graphic representations play in the educational process can be fully understood. The five particular issues raised were (a) stimulus equivalence: the necessity of ensuring that two or more media being compared portray the same information, or else, of knowing which information is unique to each, (b) graphical conventions: the need to identify and make explicit the graphical conventions that are employed either within a particular experimental manipulation or as part of the domain knowledge to be learned, (c) encoding specificity: the need to be aware of the relationship between how information is presented and how it is tested; that is, the need to acknowledge the likelihood that there will exist interactions between acquisition media and test media, (d) domain specificity: the necessity of comparing particular methods of portrayal (e.g., photographs vs. schematic line drawings) across subject matter domains as well as across different topics within the same domain, and (e) domain parsing: the need to understand how a particular domain of knowledge should be "parsed" for optimal presentation to learners of a given level of expertise. The "parse" should include a characterization of the type(s) of knowledge that are to be conveyed as well as suggestions for the type(s) of representations that would best convey them.

I also concluded that the role played by graphics in learning is in principle no different than the role played by any other information conveyance method, to the extent that all of the characteristics, constraints, limitations, and so on imposed by the information processing system itself will be imposed on all new information indiscriminately. That is, the processing of all representations would be constrained by the relevant parts of the system architecture. Nevertheless, the goal is to develop a principled means of choosing one or another portrayal method as being better suited to a particular application, and to incorporate these principles into an automated instructional design system. To achieve the first goal will require shifting the research emphasis from how a graphic portrays something (e.g., in color or monochrome; in detail or schematically) to what needs to be conveyed in the portrayal (e.g., information about structures, functions, processes and procedures, rules, etc.). Only then might a comparison across media types prove fruitful. That is, although I do not underestimate the importance of finding aptitude treatment interactions and understanding their etiology, it might do to recognize that there are other interactions - such as that between the type of information to be learned and the type of information best afforded by a given type of graphic representation - which might be more fundamental to this enterprise.

In the present section, I outline an approach toward the role of graphics in learning and memory that tries to accommodate the factors, such as domain specificity and graphical conventions, that were identified as likely to be important in

assessing the effectiveness of different methods of presenting information. I first discuss three different methods of categorizing graphics. Two -- media of presentation and amount of realism -- have been used almost exclusively (if implicitly) in past research, and the third -- type of information afforded -- is being advocated within the current approach. I then outline a conceptual framework and discuss each of its components. I argue that knowledge domains should be characterized according to the type of information needed to acquire expertise and that these characterizations should be formulated in terms of representational needs. Finally, I take the reader through a detailed example, to illustrate the most important concepts in the framework.

Categorizing Graphics Media differences and the dimension of realism. Previous efforts to construct a theoretical framework to describe the role of graphics in education have typically emphasized either physical differences between visual media or differences between types of graphic representations along the dimension of realism. In addition, as mentioned earlier, a great deal of research in education combines these two methods of categorization to investigate the relative efficiency of learning from aural or visual prose by itself versus learning when the prose is augmented by relatively realistic graphic representations. Or, learning from prose is compared with learning from some other sort of representation, such as a flowchart. With a few specific exceptions, this approach has not been a useful way to proceed.

Media differences refer to actual distinctions that exist between different physical methods of conveying visual information, such as film, TV, CRT pages, filmstrips, slides, posters, photographs, drawings, etc. Standard textbooks about using audiovisual media in teaching often discuss the media according to such physical characteristics (e.g., projected versus nonprojected media; Erickson & Curl, 1972), or else, according to pragmatic issues such as availability.

From the present perspective, it is generally inappropriate to compare different physical media unless they afford the conveyance of the same type of information or else, the stimulus equivalence issues are at least known. For instance, film and video both afford movement information directly, in real time. In contrast, line drawings afford movement information indirectly, through the use of conventions like action lines that require prior experience to interpret. Moreover, since a single drawing does not have temporality, a sequence of such drawings is necessary to convey a given movement from beginning to end, and thus, not only must information be inferred between drawings, but each drawing must be explicitly recognized as part of the previous temporal sequence and integrated within it. Thus, to the extent that information about movement is an important part of the knowledge to be conveyed within a domain, media comparisons between film or TV and more static representations like drawings may be most informative. However, this particular

example is almost an exception. For the most part, different physical media can convey the same semantic information (e.g., in the simplest case, one could present a text in almost any media, including film). Thus, although media do differ on physical dimensions like size and resolution, for the most part such physical differences are probably unimportant. This is not to ignore the fact that some media may have characteristics that make them more desirable than others. For example, a child may be able to control a filmstrip by him or herself, or a large format presentation may be more "attention-getting" than a small format presentation, or it might be less expensive or difficult to make materials in one media than another. However, these considerations are irrelevant when considering the ability of a particular medium to convey a particular type of information, which is the perspective of the present report.

On the other hand, differences in the extent to which a visual representation maintains fidelity to its referent are at least an intuitively plausible means by which some types of graphic representations might be better than others for portraying information within particular learning environments. Table 1 shows several different kinds of graphic representations and where they seem to be ordered along a realistic- abstract dimension.

<u>Type of Fidelity</u>		<u>Examples</u>
<div> <div>REALISTIC</div> <div>↓</div> <div>ABSTRACT</div> </div>	Depictive/Pictorial	3D Models, color photographs, and shaded, detailed drawings
	Schematic	Maps, monochrome line drawings, and caricatures
	Iconic	International signs and hieroglyphics
	Structural/Functional	Flowcharts, writing diagrams, blueprints, and graphs
	Symbolic	Traffic signs, logos, and symbols (e.g., sheriff's badge or skull and crossbones)
	Arbitrary	Tables, charts, and text

Table 1. Categorization of Graphics

It can be seen that, generally speaking, pictorial or depictive representations resemble their referents more closely than schematic or iconic representations, in which relations are normally correct but the objects represented are usually more abstract than their referents. It should be noted, however, that even relatively abstract representations such as flowcharts and wiring diagrams often maintain at least functional and sometimes structural fidelity to their referents. More important, much like physical media differences, the amount of fidelity that is maintained by a representation is likely to be irrelevant unless considered within the context of the purpose for which the representation is likely to be used. Thus, for example, in one of the most comprehensive investigations of the use of graphics in science education, Dwyer (1972) found that "small amounts" of realistic details added to line drawings of the heart were more effective for learning heart structures than were colored photographs of an actual heart that were presumably more realistic. In this instance, the line drawings emphasized the structures to be learned, whereas the photographs were mostly homogeneous.

Neither the medium of presentation nor the extent to which a representation is realistic can be used exclusively as a meaningful basis for categorizing graphic representations. This is because neither of these factors by itself takes account of differences in the information conveyance requirements that might be imposed by a particular subject matter domain. That is, just as encoding specificity needs to be taken into account when evaluating whether a given test is sensitive to a particular method of acquisition, researchers in graphic instruction need to be more aware of the potential influence of the subject matter per se.

Information affordances and knowledge requirements. One potentially productive way to categorize different types of graphic representations is in terms of the type(s) of information they each afford (e.g., Gibson, 1966). Having done so, it would then make sense to compare different representations against each other in terms of, for example, the directness or explicitness or efficiency with which they represent and convey particular types of information.

If graphics are to be categorized in terms of the information they afford, it is necessary to identify and possibly also categorize types of information per se. Table 2 shows a partial classification of particular types of information that different representations might convey more or less well. The types listed are principally visual in nature. Thus, for example, characteristics such as weight, smell, hardness, and the like, are not considered.

It should be emphasized that the categories in Table 2 are based on intuition, and that other classifications are certainly plausible, such as one that distinguishes between static information (e.g., objects and states) and dynamic information

(e.g., processes and stages). Ultimately, the classification that is most useful in terms of describing information conveyance needs and affordances will have to be determined empirically.

The table defines three broad classes of information, and two subcategories within each. The three classes are information about visual appearance, information about static spatial relations, and information about events and sequences of events. All three classes of information can convey a concept or part of a concept either directly or via analogy or metaphor. For example, if we know that an important structural characteristic of the solar system is that its planets revolve around the sun, then by asserting that an atom is like the solar system we are predicating that same structural characteristic to the structure of an atom (Gentner, 1983). Thus, in principle, the same representation could be used for each domain.

The distinction between primary and secondary characteristics has been made because it might be important or useful to distinguish the information or data that are directly represented from the inferences or conclusions that such data can support. So, for example, the primary characteristics listed under appearance information can, singly or in combination, support conclusions about object identity or category membership, but the latter information is not directly given by the appearance of an object. Similarly, primary information about location supports computations of distance, and information about temporal relationships supports conclusions about rate and duration of change.

<u>Type of Information</u>	<u>Primary Characteristics</u>	<u>Secondary Characteristics</u>
Appearances	shape, color size, and texture	Identity, category membership, and visual similarity
Static Relations	orientation, spatial location, and internal structure	distance, spatial proximity, structural similarity, and functional similarity
Events/Sequences	collections of objects, associative relationships, cause-effect relationships, temporal relationships, and action sequences	temporal proximity, rate of change, amount of change, duration of states, and duration of change

Table2. Categorization of Information Types

In general, once different information types have been distinguished and appropriately categorized, it should be possible to compare graphic representations to determine how well they convey each type. It is only at this juncture that different graphical conveyance methods can be categorized in terms of information affordances.

Bobrow (1975) pointed out that representations differ in the explicitness with which they afford information. Thus, there is an important difference between primary and secondary information types and the relative explicitness with which they are represented. For example, the fact that a square is an equilateral polygon is only implicit in its appearance and must therefore be derived from a pictorial representation (though it may be a trivial operation to do so).

In contrast, a propositional (or text) representation of the concept "square" could have explicit arguments stating that squares have four equal sides and angles, but then the appearance of the square would have to be derived. Similarly, a photograph, a line drawing, a film, and a text could all explicitly represent the primary appearance information that canaries are yellow, whereas, excluding the possibility that pictures can be labeled, only a text can explicitly represent the information that a canary is a songbird. Conversely, the shape of a canary is explicit in a drawing, film, or photo, whereas shape is generally only implicit in text representations. Either a text or a graphic representation may be more appropriate, according to whether one wants to convey the information that a canary is a songbird or that it has a particular shape.

Thus, even after the type of knowledge that is to be conveyed is known, it is still necessary to choose an appropriate method of conveying it, given the overall educational goal. In this view, then, an ideal communication is one in which the conveyance needs dictated by a given subject matter domain are well-matched to the affordances of the representations used to communicate them.

Sketch of a Framework

Figure 1 is a diagram of a theoretical framework that attempts to relate the influences of the domain knowledge itself, the human system architecture, the specific educational objectives at hand, known and new representational conventions, and world knowledge. The framework takes as an assumption the idea that, in general, the information necessary to achieve a criterion level of expertise in a given knowledge domain eventually needs to be characterized in terms of representational needs and specific conveyance methods. There are presently no principled or empirically-based guidelines from which to do this.

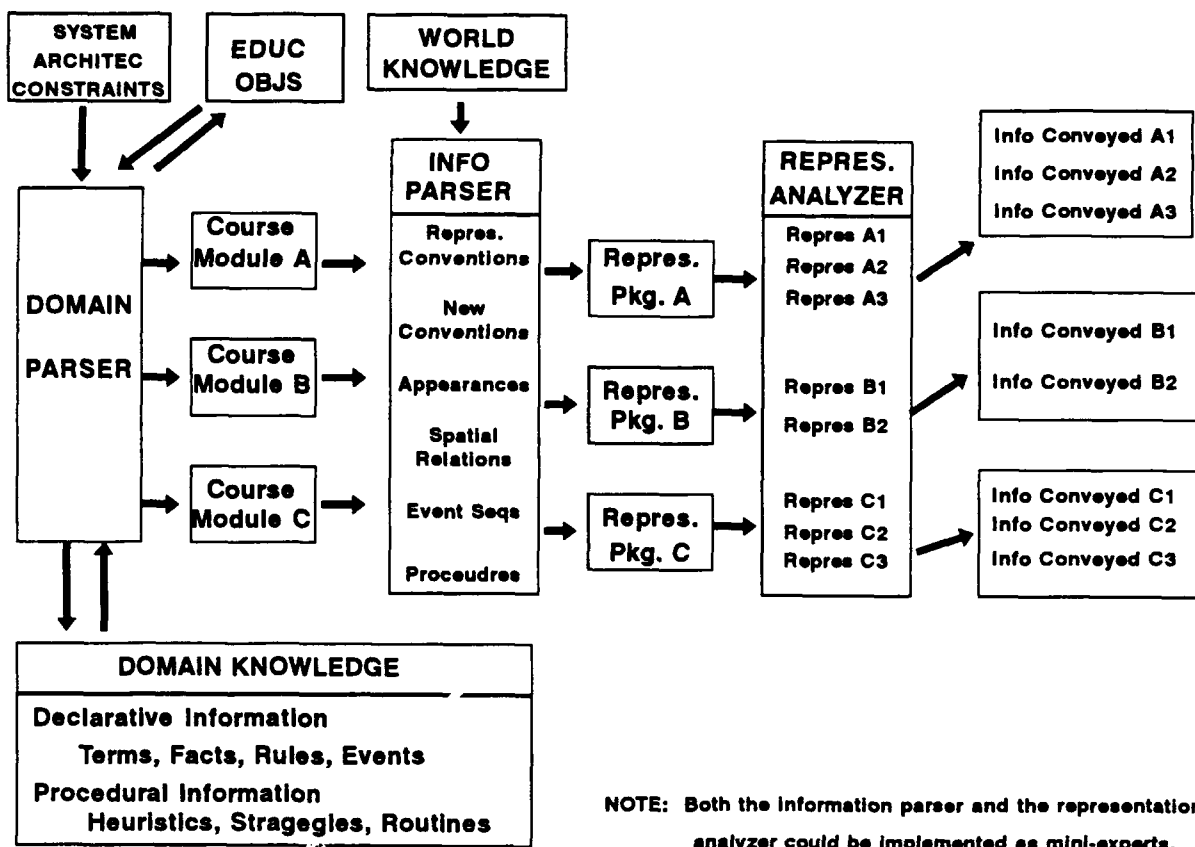


Figure 1. Theoretical Framework

Among other things, expertise in a domain entails knowing its vocabulary, terminology, facts, associative and causal relationships, laws, problem solving methods, pattern recognition heuristics and algorithms, and so on. However, referring to domain knowledge in this (conventional) way does not necessarily address specific conveyance needs. Hence, assuming that a knowledge domain has been broken down into coherent units that are to be presented in logical sequence, there still needs to be a domain parser that analyzes each unit (or lesson) in terms of conveyance needs.

The conveyance needs then need to be reformulated by an information parser in terms of the information categories in Table 2 (or some other set of empirically-justifiable categories), and recommendations made regarding the type(s) of representations best suited to each need. Thus, the representation packages that are the result of this analysis delineate the type(s) of information to be conveyed, along with suggestions about the best methods to use to do so. Several representations may be suggested for each topic.

Ideally, the suggested methods of presenting information should be implemented and analyzed according to the notion that each representation acts like an information transfer function. That is, each representation will emphasize, pass, de-emphasize,

and omit various aspects of the original information. Thus, the representation analyzer should be able to determine, for each representation, exactly what information it will convey. Different representations of the "same" information can then be compared with each other along dimensions such as ease of acquisition, interpretability, memorability, original educational goals, etc.

It should be obvious that the main work of the model is done by the two parsers. The domain parser has the task of analyzing domains or topics according to the information needed to acquire expertise, while taking account of the constraints imposed by the human system architecture as well as by specific educational objectives that must be considered. Included in educational objectives is information about the presupposed level of expertise of the targeted student population, since this is the yardstick against which criterion performance is measured.

The domain parser performs its task with a specific view towards suggesting aspects of the knowledge domain that might lend themselves to particular conveyance needs or methods. Under normal circumstances, domain knowledge is not characterized according to this perspective. Indeed, at best, domain knowledge is characterized according to the conclusions, or secondary characteristics, that need to be acquired. For example, domain knowledge is often broken down into that which is declarative (e.g., facts; rules; laws) and that which is procedural (e.g., motor skills; problem solving heuristics or algorithms), yet this particular breakdown is normally neutral with respect to representational issues. Thus, the domain parser has to parse any "conclusion needs" into packages that are appropriate for specific conveyance methods and hence, for specific types of representations.

It should be noted that the domain parser should be able to request more knowledge about the domain under consideration, including knowledge about the relative importance of various pieces of information. In addition, it should be able to request modifications of educational objectives, if current objectives are perceived as difficult or impossible to implement.

The information parser categorizes each piece of knowledge from the domain parser according to its probable information type. Sometimes, two or more types of representations might be suggested for a given piece of knowledge. For example, suppose the information that a water molecule is composed of two hydrogen atoms and one oxygen atom is to be conveyed. The formula $2\text{H}^+ + \text{O}^{2-} = \text{H}_2\text{O}$ represents this information as a quantitative relationship; there is an equality between the valences of the three ions on the left and the molecule on the right. Underlying this quantitative relationship, however, is a structural one involving the numbers of electrons that are permitted to be in orbitals at different mean distances from a nucleus. It is not clear, a priori, whether the formula representation or a graphic representation of the atomic structure is more appropriate here,

so both might be suggested.

The information parser should also have a category for new graphical conventions that might need to be learned. To be able to discern such new conventions, and to facilitate suggestions for representations, the information parser must have access to information regarding representational conventions in general. It also must have world knowledge (at a level appropriate to the targeted student population), to be able to determine what structural and functional analogies might be appropriately used in the representations it suggests.

The information conveyed by each representation can ultimately be compared to the original domain knowledge, to the educational goals, to the criterion performance of some target population, etc. As more is learned about the success with which various representations convey different types of information, this knowledge can be input back into the system as further constraints on both parsers.

It should be obvious that the necessary empirical information to create a working implementation of either the domain parser or the information parser is missing from the literature. However, it is hoped that the current framework can provide a guideline for identifying the type of data that would be useful to acquire in the service of such an implementation.

An Example From Biology

Suppose that one lesson in a typical university introductory biology class is centered around the structure of DNA and how it replicates, and that the following information, which has been distilled from an introductory biology textbook (Alberts, Bray, Lewis, Raff, Roberts, & Watson, 1983), is the input to the domain parser:

The DNA molecule is a two-stranded polymer composed of four different nucleotide bases: adenine (A), cytosine (C), guanine (G), and thymine (T). Specific hydrogen bonding between G and C and between A and T causes complementary base pairing in which each member of a base pair is located on opposite sides of the two-stranded helix which is the DNA structure. The nucleotide bases are located on the inside of the helix.

DNA replication entails a separation of the double helix, with each strand acting as a template for the formation of a new molecule. Nucleotides are added to the parent template sequentially by a process that requires them to form complementary base pairs. Daughter strands are complementary in sequence to their parent template strand, so that each replication duplicates the genetic information entirely.

This particular set of facts is declarative in nature, and the domain parser might choose to represent them using a propositional format. The job of the domain parser is to break

this information up into units that have coherence and yet that are amenable to being described in terms of conveyance needs, or, better yet, information types. For example, if the information above were passed through the parser, it might be broken up into smaller parcels, such as:

- (a) The DNA molecule is a two-stranded polymer that is shaped like a double helix.
- (b) The molecule is composed of four different subunits: adenine (A), cytosine (C), guanine (G), and thymine (T).
- (c) There is specific hydrogen bonding between G and C and between A and T (i.e., the members of a pair "fit together" molecularly). This is called "complementary base-pairing." (d) The nucleotide bases are located on the inside of the helix, with each member of a base pair on opposite sides.
- (e) To replicate, the double helix must separate into two strands.
- (f) Each parent strand acts as a template for the formation of a new DNA molecule.
- (g) Nucleotides are added to the parent templates one at a time by a process that forms complementary base pairs.
- (h) Daughter strands have a nucleotide sequence that is the complement of their parent's, so that each replication duplicates the genetic information entirely.

We shall further suppose that, much as the original information is presented in two paragraphs, the parsed information will be output in two information packages, one containing points [a] through [d], and the other, points [e] through [h]). There will be suggestions within each information package regarding conveyance needs. For example, in the unit consisting of facts [a] - [d], there is an obvious need to convey information about an event. The facts, together with the suggested conveyance needs, are passed on to the information parser.

Given such strong hints, the information parser would corroborate the suggestions of the domain parser, and identify several additional primary information types within each of the two information packages. In the current example, there may be information to be conveyed about new representational conventions (e.g., the chemical notation for molecular bonding), as well as appearance and identity information (the shape of the double helix; the molecular structure of the bases), spatial relation information (the location of the nucleotides on the strands; complementary base pairing), and event information (separation of the parent strand; sequential addition of complementary nucleotides to the daughters).

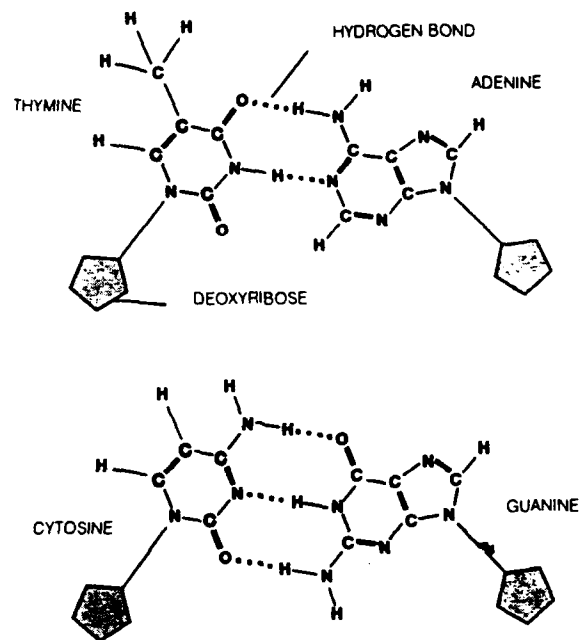
The information parser might also identify and include in its output an analogy or metaphor for one or more of the information types, based on its world knowledge. For example, it might suggest that a spiral staircase could serve as an appearance analogy for the shape information, a "lock and key" metaphor could serve as a functional analogy for the complementary base pairing idea, and a zipper could serve as a process analogy for the beginning step of the DNA replication process.

Finally, the information parser will make suggestions about how to best represent the information it has parsed. In this case, for example, it might recommend that both structural and relational information about complementary base pairing (point [c]) be combined in a single diagrammatic representation, partly because the base pairing idea is somewhat complex and partly because it will involve relatively unfamiliar notation. The remaining appearance and spatial relation information (points [a], [b], and [d]) might then be combined into a second representation.

Once the information parser has made its suggestions, they must be implemented in actual representations. The parser might suggest several alternatives for implementing each of the representations it has suggested. Until there is more knowledge about the information affordances of different types of representations, it will probably be useful to implement more than one instance of each suggestion, and to make a choice based on the output of the representation analyzer. The representation analyzer should allow selections of which representatives to use to be based on the specific information that is conveyed by each.

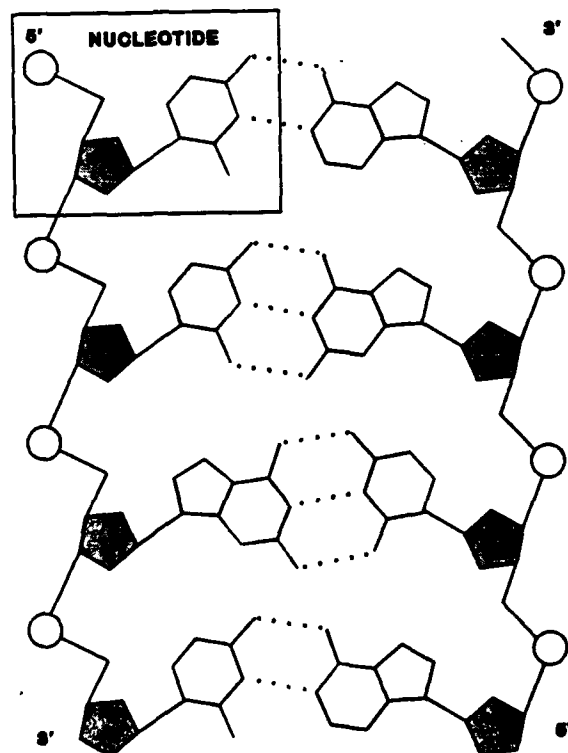
To illustrate how graphic representations of the same subject matter portrayed in the same physical media with the same relative level of realism can nevertheless afford quite different information, I would like to end this section with some examples of figures that are meant to convey some or all of the information stated in points [a]-[d] above. Though all of the figures share a lot of "surface" similarities, they nevertheless do not afford the same data.

Figures 2-5 show four different ways to represent some of the ideas inherent in the concept of complementary base pairing, and Figures 5-7 show different representations of the structure of DNA. All of the figures are black and white schematic line drawings with at most two additional colors used for highlighting. I wish to make no judgments about the relative merits of these figures; indeed, that is an empirical issue to be decided in the context of information about particular educational goals, student aptitudes, other simultaneously available representations (e.g., text), etc.



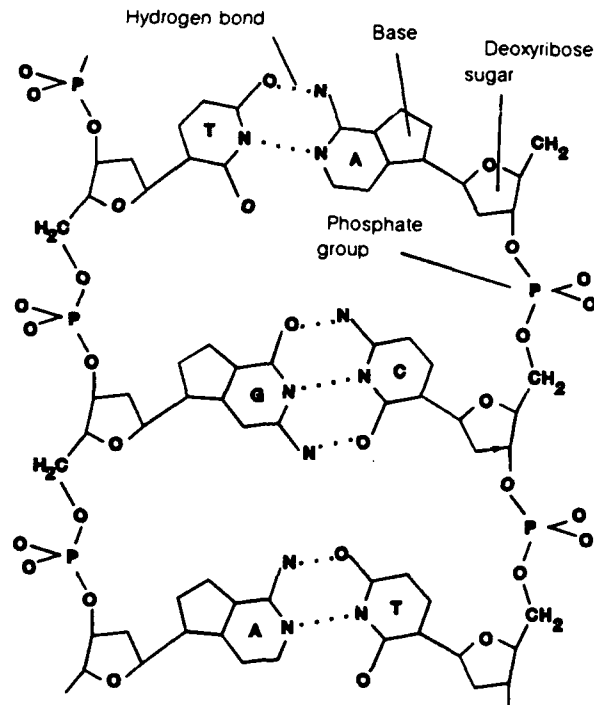
(Adapted from Felsenfeld, G. 1985. DNA.
Scientific American, Volume 253, pages 58-67.)

Figure 2. DNA - Hydrogen Bond.



(Adapted from Felsenfeld, G. 1985. DNA.
Scientific American, Volume 253, pages 58-67.)

Figure 3. DNA - Nucleotide.



(Adapted from Purves, W.K., & Orians, G.H. 1983.

Life: The Science of Biology, Boston, MA: Willard Grant Press.)

Figure 4. DNA - Molecular Bonding.

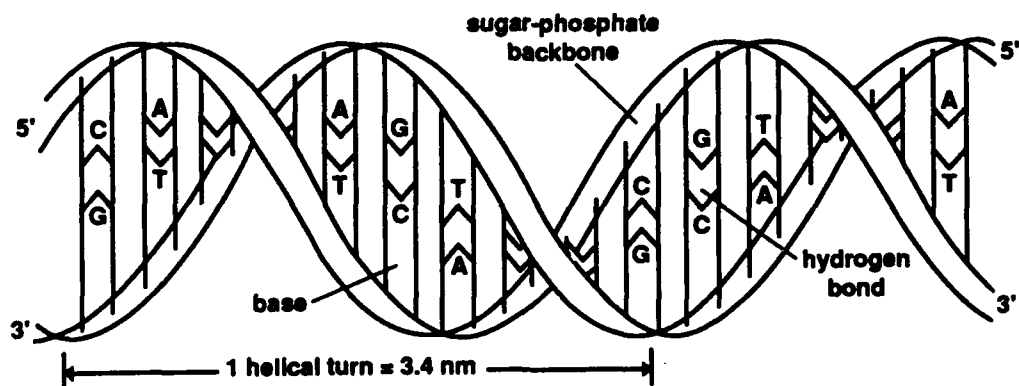


Figure 5 Adapted from Alberts, B., Bray, D., Lewis, J., Raff, M., Roberts, K., & Watson, J.D. (1983). Molecular Biology of the Cell. NY: Garland Publishing Co.

Figure 5. Double Helix Structure

In terms of information conveyed, Figure 2 depicts only the two base pairs, but uses chemical bonding notation and is thus specific with respect to the molecular structure and the location and type of hydrogen bonding between bases. In contrast, Figure 3 omits these details by representing the bonding schematically, while at the same time, it places the base pairs in the context of a portion of the DNA molecule as a whole. Thus, although the specifics of the hydrogen bonding are omitted in Figure 3, some additional structural information is conveyed. Figure 4, on the other hand, conveys a combination of the information from Figures 2 and 3, insofar as the specifics of the molecular bonding are included along with contextual information about the structure of DNA.

Figure 5, like Figure 3, conveys the bonding between base pairs schematically, yet it also conveys information about the shape of a double helix (point [a]), and about the location and identity of the nucleotide bases (points [b] and [d]). In addition, it conveys information about the specificity of the bonding via a visual analogy that somewhat poorly instantiates the lock and key analogy, since it appears as though A is as likely to bond with G as it is with T.

Figures 6 and 7, like Figure 5, are also representations of the structure of the DNA molecule. Whereas both 6 and 7 convey some information to the effect that the molecule is three-dimensional, Figure 6 emphasizes the arrangement of the atoms that comprise the DNA molecule, whereas Figure 7 again emphasizes that pairwise structure of the bases that make up the double helix.

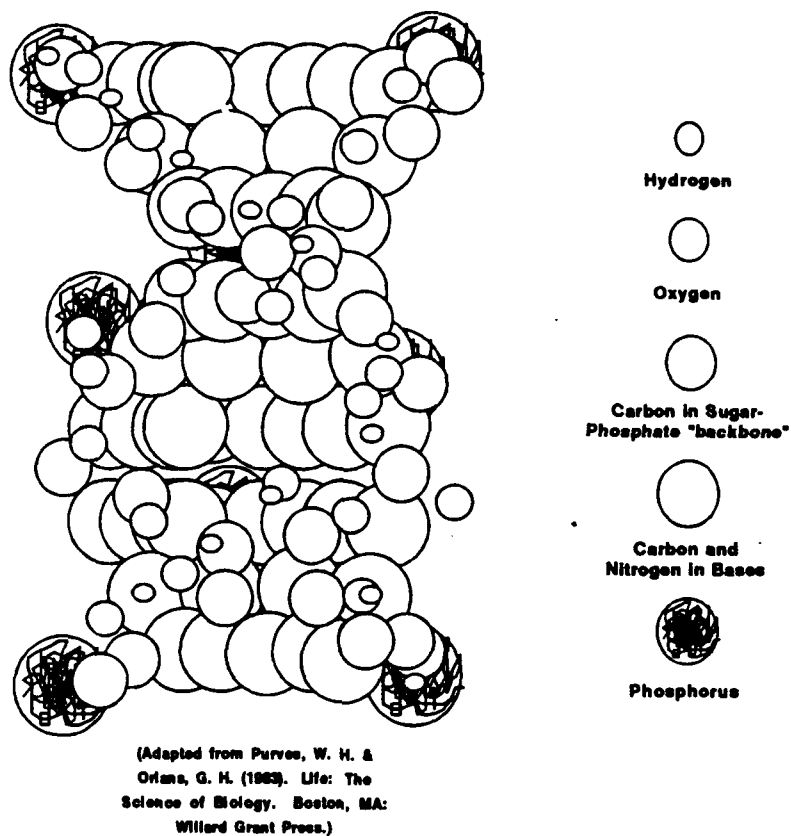


Figure 6. DNA - Atomic Structure

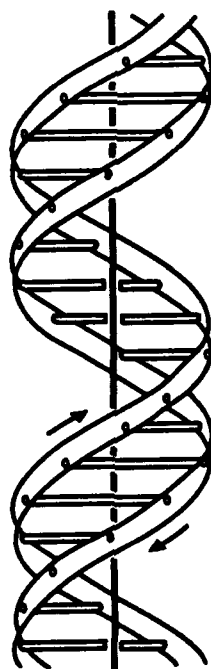


Figure 7. Pairwise Double Helix

It should be clear, from just these few examples, that relatively subtle differences between representations (e.g., compare Figures 3 and 4, and Figures 5 and 7) can nevertheless result in the conveyance of different information, both in the quantitative and qualitative sense. We are quite a long way from implementing an information or domain parser. Most previous research has implicitly concentrated on questions about the representation analyzer and the transfer functions; that is, most research has compared the educational results of learning from different types of representations. What is needed at this juncture is research that is focused toward discovering the principles underlying the construction of representations that achieve particular information affordances. In addition, research is needed which can give us guidelines for reformulating domain knowledge in terms of conveyance needs.

General Conclusions

The effective use of graphics in education requires good models of the domains to be learned as well as good models of the learners. In particular, we need to know what information should be conveyed from a domain to achieve specific educational goals, what constraints are imposed by the system architecture of the learner, what conventional and world knowledge can be assumed and what must be explicitly taught, what role individual differences might be expected to play in the process, and what type of information is best conveyed by different graphic representations. At present, we have only partial knowledge about any of these factors, and in some cases, none at all.

The proposed framework is an attempt to clarify the interaction that can be expected to occur between conveyance needs that may be domain-specific, representational methods that differ widely in terms of what they are capable of conveying, and a receiver environment that will change as a function of prior knowledge and current and desired level of expertise.

It should be clear that much research is still required to understand the role of graphics in education. In addition, research is needed to validate the general and specific assumptions of the framework. It should be noted that the framework itself stands as a set of guidelines for this research. It also stands as an exhortation about attacking old problems in new ways that incorporate more about what are known to be psychologically relevant factors.

It seems fair to say that the commonly held belief regarding the utility of graphic representations under almost any circumstance needs to be questioned. Indeed, it will be useful to identify those domains for which graphic representations are not necessary for the effective conveyance of information. Similarly, it seems fair to say that complexity is not always a necessary feature of an informative representation, and that the conditions which warrant simpler displays need to be identified.

III. RESEARCH ISSUES FOR AIDA (Polson)

Introduction

In framing the research issues, I decided I should consult an SME (Subject Matter Expert). I visited with Brian Dallman of the Air Training Command's Technical Training Center at Lowry Air Force Base. Dallman is the Wing Training Applications Officer and has approximately 20 years of experience with computer-based training in the Air Force. He identified five areas which he believes are of major concern in the development of computer based Air Force training materials and courses:

1. Use of Visual Materials
2. Evaluation
3. Interactive Courseware Design
4. Task or Instructional Analysis
5. Human Computer Interaction

These areas are either cost drivers (i.e., they are very expensive to implement), and/or they are very difficult to do well and consequently are frequently done badly. They are, therefore, potential target areas for an AIDA. The first of these areas is addressed at length in Section II of this report. I shall summarize issues in each of the above five areas in the remainder of this section.

Use of Visual Materials

Dallman estimated that at least 50% of the development effort for computer based instructional materials is devoted to graphic materials and despite that, visual materials are still not well utilized. The sources of the problems can be from

- a) inappropriate use of graphics, i.e. using the wrong type of graphic,
- b) overuse of graphics, i. e. using graphics when they are not necessary to convey the information, and
- c) underuse of graphics, i. e. failing to use graphics because they are time-consuming and difficult, when, in fact they are the best way to communicate the information.

Friedman's Section II of this report very thoroughly addresses the issues of implementing automated or semi-automated use of visual materials from a cognitive perspective.

The following research questions, which are drawn directly from Friedman's remarks, are framed with respect to graphics or visual materials specifically. However some of the issues pertain to any type of instructional material in an AIDA type of framework.

The issues or research questions are organized into three categories:

- 1) Cognitive architecture issues that stem from questions related to how people process information;
- 2) Methodological issues related to research in the educational use of graphics;
- 3) Issues that arise from the specific approach suggested by Friedman which corresponds in many ways to the current framework being proposed for the AIDA system(s).

Cognitive Architecture Issues

Working Memory. As discussed in Section II (see Friedman's remarks on working memory, pp.) and in Volume I of this series (see Sections II and III by Polson and Tennyson) working memory has a limited capacity. Only a few "chunks" of information can be held in memory at once. Learning is impeded if the student cannot hold the material being presented in working memory so it can be processed and stored in long term memory or if the prerequisite knowledge to process the piece of information being presented exceeds the capacity of working memory. However what constitutes a "chunk" may vary with level of learning and expertise in a topic, topic domain, type of presentation (textual vs. graphic), and other factors. In giving advice to an instructional designer or trying to design an automated instructional design system, what constitutes a "chunk" for a given student in a given domain becomes a crucial question. The following research questions are concerned with this issue of chunking with respect to visual materials.

1. How should graphics materials be chunked for presentation in a learning task?
 - a. How do chunking units change with expertise?
2. Are there chunking principles for graphics that generalize across substantive domains?
3. For the same content, are the chunks for graphics and text the same? Are the principles for determining the chunks the same?
4. What kind of redundancies should be built into a graphic to facilitate chunking (e.g., color coding)?

Long-term Memory. Long-term memory can be viewed as a "tangled-hierarchy" of linked knowledge structures (Anderson, 1983), which may include a number of different representational types, productions, propositions, spatial representations, temporal

strings, and schemata or frames. These knowledge representations encapsulate a variety of different types of knowledge including declarative, episodic, procedural, strategic, contextual, and causal knowledge as well as our mental models, situational models, and general world knowledge. The declarative knowledge includes various types of world knowledge including social conventions, conventions about information being processed (e.g., English is read left to right), and various graphical conventions such as occlusion signals depth. For new information to be readily accessible and useable it must be integrated into the previously existing long term memory knowledge structures. Following are some research questions concerning graphics that relate to the long term memory structures.

1. What are the set of graphical conventions?
 - a. General (e.g., perspective; size-distance relations; action lines)
 - b. Domain-specific (e.g., maps; blueprints; schematics)
2. Which conventions may be assumed to be known by a given subject population? Which should be taught? When?
3. What properties of graphics can be exploited to facilitate making analogies between known information and new information (e.g., atoms = solar system) so that the new information can be more readily integrated into our existing knowledge structures.
4. How do people integrate information presented graphically with information presented in text?

Processing Resources. It is generally accepted that resources for processing information are limited such that if the resource demands of information processing exceeds the resource capacity, performance will be degraded. Prior to 1979 it was assumed that all processes competed for resources from a single undifferentiated pool, and, therefore any two types of concurrent processing could potentially lead to performance degradation if the demand for resources exceeded the capacity.

In an influential paper, Navon and Gopher (1979) proposed that there are multiple types of qualitatively different resources, each with a limited capacity. Processes which use the same type of resource can potentially interfere with each other because of competition for scarce resources, but processes which use different types of resources will not. Navon and Gopher did not delineate the potentially necessary and sufficient set of resource types that would characterize the human information processing system, which is a short-coming of their model.

However, Wicken's (1984) and Friedman and Polson (1981) have each proposed possible sets of multiple resource types. In each

model, different types of coding or representation (verbal vs. spatial) would potentially draw upon different resource pools, which possibly has educational implications. Wicken's model was primarily developed for explaining and predicting performance in complex tasks, while Friedman and Polson's model was developed in the context of the cerebral specialization issue, but all three frameworks have focused on the performance implications of these models rather than the educational implications.

The educational implications of these models stem from the issue of whether learning, retention, and utilization of information is improved if information is processed and stored in more than one code (representational type) and the extent to which different presentation methods (text vs. graphics or auditory vs. visual) result in different types of encoding. Two specific research issues related to the development of an AIDA are:

1. What kind of redundancies can graphics provide for learning from text?
2. Is it more resource-efficient for graphics to be redundant or nonredundant with text? How might this interact with expertise?

Methods Issues

There are number of different methodological issues which need to be resolved before research in the educational implications of graphics can advance significantly. Friedman has identified five categories of methodological issues:

A. Stimulus Equivalence:

How do you ensure that information in graphics and information in text are equated? How does one represent the information content of a graphic?

B. Encoding Specificity:

How do you appropriately test what is learned (e.g., recall measures may not tap what was derived from graphical input)?

C. Domain Parsing:

How do you "parse" a domain into appropriate modules for learning?

D. Graphic Conventions:

1. What are the graphical conventions used in any stimulus display?
2. How can they be identified and improved?

3. How might they distort research findings if they are not equated in research materials?

E. Domain Specificity:

How do principles of graphics in information transmission generalize across courseware modules within a domain and across domains? Do graphic principles differ across different types of knowledge (declarative knowledge and procedural knowledge, for example)?

Issues Related to Friedman's Framework

Friedman has proposed a framework for an AIDA system which would provide guidance on graphics and visual information. The framework assumes that an empirically determined method of categorizing graphics can be developed (e.g. realistic to -- abstract). Further, it assumes that for each type or category a determination of the type of information that it conveys can be accomplished. The AIDA framework proposed by Friedman consists of three modules: 1) a domain parser, 2) an information parser, and 3) a representation analyzer (Figure 1).

The domain parser takes into account information about: 1) the constraints imposed by the nature of the architecture of the human information processing system such as short term memory limitations, processing resource types and limitations, nature of long term memory, etc.; 2) the educational objectives; and 3) the domain knowledge. In this framework, it is assumed that the domain knowledge has already been organized into coherent units that are to be represented in a logical sequence which presupposes some type of knowledge acquisition system. The domain parser analyzes the domain knowledge in terms of the information that needs to be conveyed and parsed into units that are appropriate for specific conveyance methods and therefore specific representations.

The information parser can be conceived of as a "mini-expert" which has knowledge about representational conventions, the different categories of graphics and the amount and quality of information that each type of graphic can convey. With this information available, the information parser analyzes the information units of the domain parser and determines the best representational type or may suggest two or more alternative representations.

The representational analyzer then determines for each representation exactly what information it will convey. If more than one representation has been suggested for a given bit of information, the information analyzer can point out the differences so that decisions can be made on how the differences will impact ease of learning, educational objectives, etc. It should be noted that Friedman acknowledges that we do not

currently have the necessary knowledge to implement such a system. The following questions would need to be answered:

A. Graphics categorization:

How should graphics be categorized (see Table 1)?

1. Continuum from realistic to abstract? or
2. Other possible categories?

B. Information Content of a Graphic:

What sort of information does each type of graphic convey (see Table 2)?

1. Primary characteristics (e.g., appearances; states)?
2. Secondary characteristics (e.g., category & event information)?

C. Domain Parser:

How do you implement a Domain Parser? When in this process should choices be made about graphical representations?

D. Information Analyzer:

Given certain information transmission needs in a courseware module, what type of graphic is best? How can this be implemented in an "expert" Information Analyzer?

E. Representation Analyzer:

What information will a given representation transmit, omit, enhance or subtract from? How can a Representation Analyzer be implemented to enable this "transmission profile" to be identified?

Evaluation

The issue of Evaluation has two aspects. The first aspect is probably better termed "technology assessment" (Baker, 1988) and is concerned with the evaluation of the system or its subcomponents. While the AIDA project should include plans for how assessment will be achieved, the research issues of technology assessment are beyond the scope of the project. However, research issues of computer based training systems technology assessment are within the scope of the Training Systems Division. Baker (1989) has made the case for the importance of this issue quite nicely.

The other aspect of evaluation comes under the heading of student assessment or diagnosis. In even simpler terms it can be

labeled "testing". The issue of how to give design guidelines for student assessment or how to automate the testing process has been notably absent from any discussions to date, but is a key part of the instructional process and one which novice or even intermediate level instructional designers have a great deal of difficulty doing well, particularly in a computer based training environment.

Student Assessment is an issue which I think could well be approached in the same manner as was the use of visual materials. Kurt VanLehn (1988) has done an excellent job of identifying the issues and methods of student diagnosis for intelligent tutoring systems, but it is my understanding that for the near term, AIDA is conceived as an advisor for more traditional computer-based training systems. A commissioned or in-house study could be done which reviews the problems, frames the issues in terms of cognitive processes, and then outlines a framework for automating the process. From that paper, the detailed research issues which need to be solved in order to automate student knowledge assessment can be identified.

For the near term needs, the study should identify the existing methods, determine the types of knowledge for which they are appropriate, rate or evaluate their effectiveness and assess the extent to which they can be formalized as a set of rules for a mini-expert system so that the project managers can assess what is feasible to implement at this time. My interpretation of Friedman's remarks in Section II is that automation of the use of visual materials is not feasible at this time, nor are there many principled guidelines that can be used in a graphics advisor. It is an open question as to the extent to which this is true for student assessment.

Interactive Courseware Design

The cognitive science perspective on the educational process emphasizes the active acquisition of knowledge structures by the learner (see Volumes 1 and 2 in this series). The objective of having courseware or systems which engage the learner in processing the information being presented is to facilitate and encourage the learner to actively process the information so that it becomes integrated into her existing long term memory knowledge structures. While this is a desirable goal, the typical novice computer based courseware developer, who is accustomed primarily to a classroom lecture mode of instruction, probably has few notions of how to accomplish this goal. Because of their inherent interactive nature, this is not an issue with intelligent tutoring systems, although the systems do vary along this dimension.

The AIDA aspect of this issue can be approached in the same manner as recommended for student assessment, using the Friedman's remarks as a model. As recommended for the student assessment issue, the study would need to assess what currently

could be automated, as well as identify the research issues and the nature of a system.

The second approach to this issue, and which I want to advocate, is not specifically tied to an AIDA, but is a more general issue in the use of computers in instruction (this is my look to the future pitch). My suggestion for a direction of research is to investigate alternative ways to use computers in education which have the objective of actively engaging the learner in the task. By this, I do not mean "intelligent" systems in the sense that they have an expert model, a student model, etc. For instance, the use of cooperative groups in computer-assisted instruction is one possible research area (see Kintsch's principles 6 and 7 in Volume 2 of this series). Another area is the use of the computer as a "scaffolding" or support tool to reduce short term memory load and let the student explore various solutions to a problem that she could not have accomplished without support. These types of tools encourage the learner to reflect upon her own problem solving processes. Burton (1988) labels these "empowering tools." The algebra tutor being developed by W. Kintsch and his students is an example of such a system (W. Kintsch, 1989; Nathan, 1989).

Task or Instructional Analysis

Of the five areas of concern, Task Analysis is the only one which has received any emphasis in the AIDA discussion and papers to date. This is an extremely critical area since, if it is not done correctly, it will be difficult, if not impossible, to do a first rate job on the rest of the instructional task. I am not going to try to address the research issues here since they are being addressed by others (see for example the chapter by Tennyson in Volume 5 and Merrill's remarks in Volume 6). However, I will point out that the Domain Parser in the Friedman system which was discussed earlier would be a part of any module to do a task or instructional analysis and the same research questions apply.

As a word of caution about how extremely difficult and expensive implementing this aspect of an AIDA can be, I will point out that the rather ambitious and expensive tri-services project for automating knowledge acquisition met with only limited success. Automating knowledge acquisition for an instructional system is even more difficult than automating knowledge acquisition for an expert system because of the necessity for "decompiling" the knowledge of the expert and the necessity for "propaedeutic" representations (Halff, 1988).

While task analysis is amenable to the same approach as used for visual materials, I hesitate to recommend it until the results of this cycle are completed. If sufficient details about how this should be done are gathered in this cycle, it may not be necessary. Also research on other parts of the system could be

conducted without having the task analysis aspect of the system functional. One or more test data bases could be implemented in which the task analysis had been done in the traditional manner.

Human Computer Interaction

The fifth and final area of concern has at least two aspects. The first is the traditional interpretation of this area: How do you construct the interface to an instructional system such that the interface itself facilitates rather than impedes the instructional process? Miller (1988) has addressed these issues for Intelligent Tutoring Systems and the majority of what he has to say also applies to any computer based-training system. As with the technology assessment issue, I don't believe the research aspect of this issue falls within the scope of this project. In contrast to the technology assessment area, I don't believe it even falls within the domain of the Training Systems Division. Designing a system which gives design advice for interfaces is at least as complicated as designing an AIDA. However as a design issue it needs to be taken into account when developing the specifications for an AIDA system. The interface of AIDA should facilitate the instructional design process, not impede it.

There is a second aspect of this area, which I do believe is very relevant to this project, both as a research issue and as a design issue. How do you decide what aspects of a task the computer should do and what aspect the human should do? In terms of the design of computer-based instruction, it is a question of how much control the computer should have over the learning process and how much control the human should have for optimal learning and transfer. In terms of implementing an AIDA, the question becomes what should we have the computer do and what should the instructional designer do? I feel that there has been little consensus on that issue to date. However, making that decision is absolutely necessary before any specifications can be developed.

IV. CONCLUSION (Spector)

Perhaps it is no surprise that there are so many unsolved problems with regard to the automation of instruction. After all, what we know about the mind and how people learn is still somewhat limited even after a half century of intensive research. We know that people apparently store textual information differently than they store visual information (Anderson, 1983). However, we cannot say definitely how the storage takes place, nor can we identify the specific physiological structures involved in the process. In short, we do not know how to program brains. That we should expect to program instruction with great efficacy is perhaps premature.

What can be done is to develop principled mechanisms to explore the questions raised in this report and elsewhere (Glaser & Bassock, 1989). An Advanced Instruction Design Advisor that provides automated guidance to courseware designers and also automates the process of developing and delivering instruction to students can provide an important platform for the kind of research proposed in this report. The advantages of such a platform are that:

1. The means of delivering instruction can be held constant while various instructional prescriptions are implemented and tested;
2. Instructional prescriptions can be easily incorporated into an AIDA and tested because AIDA provides for the rapid prototyping of courseware;
3. As knowledge about human learning progresses, new principles and prescriptions about learning and instruction can be incorporated; and
4. The areas where knowledge is highly limited (e.g., how to optimize the use of graphic representations, how to optimize the use of auditory representations, etc.) can be addressed in discrete modules and elaborated as knowledge progresses.

There are surely additional advantages to be gained from proceeding with the AIDA research program (e.g., the economic advantages that may accrue if AIDA is successful). However, what is basic to the AIDA project is that it is an attempt to provide instructional design guidance to subject matter experts responsible for developing effective computer-based courseware. There are some instructional strategies and tactics that are common to lecture-based and computer-based settings. However, the computer provides an environment in which new instructional methodologies can be implemented (e.g., interactive and individualized simulations, adaptive testing, learner controlled exploratoriums, and so on). To take full advantage of these new possibilities, the research proposed herein should proceed along with the continuing work to develop an AIDA.

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